Un nouveau cadre conceptuel pour évaluer la contribution des filières agricoles au développement durable des territoires – application à la filière avicole réunionnaise

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THESE DE DOCTORAT

Présentée par

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Pour l'obtention du grade de

DOCTEUR DE L'UNIVERSITE DE LA REUNION

Discipline : Sciences économiques

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soutenue le 23 Avril 2014 devant la commission d'Examen

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Ces travaux de thèse ont été financés par l'ANRT, Crête d'Or Entreprise et le CIRAD (UMR SELMET)

<u>Pour citer cette thèse:</u>

Thévenot, Alexandre. 2014. Un nouveau cadre conceptuel pour évaluer la contribution des filières agricoles au développement durable des territoires – application à la filière avicole réunionnaise. Thèse de Doctorat, Université de la Réunion, Saint-Denis, Réunion.

Remerciements

Avant de vous présenter le fruit de ces 3 années de labeur, je tiens avant tout à remercier l'ensemble des personnes qui ont contribué d'une manière ou d'une autre à l'aboutissement de ce travail.

Tout d'abord, j'aimerais remercier les personnes qui m'ont encadré, guidé et soutenu pendant ce travail de thèse. Merci donc à Yves Croissant pour avoir accepté cet encadrement et pour ses encouragements tout au long du processus. Un grand merci à Jonathan Vayssières qui a largement contribué au montage de ce projet et à l'obtention de son financement. Merci également pour m'avoir encadré scientifiquement de bout en bout depuis maintenant plus de 5 ans au sein du CIRAD. Ta disponibilité, ta patience et tes encouragements ont été cruciaux au bon déroulement de cette thèse. J'espère que l'encadrement de ton premier thésard aura été aussi bénéfique qu'il l'a été pour moi.
Merci à Emmanuel Tillard pour m'avoir accueilli au pôle élevage et pour l'appui tant statistique que logistique qu'il m'a fourni. Merci à Philipe Lecomte pour m'avoir encouragé tout au long de mon parcours. Enfin merci à Gisèle Morel pour la gestion administrative et financière de cette thèse.

Je remercie bien sûr mes encadrants chez Crête d'Or Entreprise : François Gauvrit pour m'avoir offert l'opportunité de réaliser ce travail et pour avoir toujours répondu présent aux réunions d'étape. Un grand merci à Adeline Vion pour ses conseils, sa disponibilité, et pour avoir grandement facilité la mise en relation avec les personnes ressources dans la filière.
Je n'oublie pas l'ensemble des acteurs de la filière qui ont également contribué à décrypter et quantifier cette filière. Merci particulièrement à Cyrille Pasquier de l'URCOOPA, Miguel Fontaine de Couvée d'or, Jef Reichardt d'Avipole, Gérard Marck de SICA des sables et également les plus de 70 éleveurs qui ont été enquêtés durant ce travail.

Je tiens ensuite à remercier mes rapporteurs Jean Lossouarn et Véronique Alary pour la relecture de mon manuscrit et pour leurs remarques constructives. Merci également à Jean

Champagne, Tom Waassenar, et Alexis Parmentier pour leur participation à mon jury de thèse et à l'intérêt qu'ils ont manifesté pour mes travaux.

Je tiens à remercier les membres de mon comité de thèse qui ont accompagné avec une grande ouverture d'esprit l'évolution du questionnement. Plus spécifiquement, je veux souligner l'aide de Joël Aubin, Catherine Macombe, François Guerrin qui ont enrichi mon discours et proposé de nombreuses idées intéressantes pour améliorer et approfondir mon sujet de recherche.

Un grand merci à Laure-Hélène Ribola et Lucie Ploquin pour leur appui précieux dans la collecte et le traitement de la masse de données assez extraordinaire qu'a requis cette thèse.

Merci à David Berre pour ces discussions stimulantes à propos de tout. Sans vouloir me faire l'avocat du diable, LCA-DEA a de l'avenir.

Merci à tous les stagiaires, VCAT, VSC, et doctorants du CIRAD Saint Pierre pour avoir contribué de près ou de loin à m'évader du boulot en rando, plage, ou soirée. Merci plus particulièrement à tous ceux qui sont passés par le pôle élevage : Mathieu (les Pétr… se portent bien mieux ici depuis que t'a arrêté de les vendre sur leboncoin), Ingénieur Maeva, Adolfo, Stéphanie, Jery, Caro, Amandine (Buuuurp), Céline, Yvane, Cyprien.
Merci également à tous les dalons du surf : Simon Terrasson, Ludo, Clément, David, Pierre, Sam, Thomas. Keep safe, ça rode la dessous ….Nartrouv' au peak.

Je remercie également toute ma famille pour leur confiance, leur soutien et leurs encouragements tout au long de ces années d'études.

Enfin *last but not least*, je voudrais remercier du fond du cœur Camille pour m'avoir soutenu durant ces trois années. J'ai conscience d'avoir été parfois irritable, désagréable, entêté….merci pour m'avoir épaulé à chaque instant dans les moments les plus difficiles.

Résumé

Parvenir à la sécurité alimentaire dans un respect des écosystèmes planétaires et des sociétés humaines reste un des grands défis des prochaines décennies. Les filières agricoles sont potentiellement des leviers puissants pour repenser les modes de production et d'approvisionnement en produits alimentaires. Elles font donc actuellement face à de fortes pressions pour intégrer le développement durable dans leur stratégie. En ce sens, les décideurs industriels et politiques sont fortement demandeurs de méthodes pour évaluer de façon systématique à la fois les impacts et les services rendus par les filières aux écosystèmes et aux sociétés.

Cette thèse propose un cadre conceptuel permettant de mesurer le progrès d'une filière agricole en matière de contribution au développement durable de son territoire. Ce cadre conceptuel comprend une analyse stratégique du territoire en vue de l'identification collective d'enjeux et de mesures d'amélioration techniques et organisationnelles. Il incite à une quantification et une spatialisation des effets dans un objectif d'équité interterritoriale. Il est recommandé d'inclure dans l'analyse les différentes parties prenantes généralement impliquées: les fournisseurs, les concurrents, l'environnement industriel et la communauté. Sur la base de théories de management stratégique des entreprises, il est possible de réduire le nombre de parties prenantes à considérer afin de concentrer l'analyse sur les plus concernées par les mesures d'amélioration. Ce cadre conceptuel intègre potentiellement de nombreuses méthodes d'évaluation déjà reconnues et disponibles dans la littérature pour peu qu'elles répondent à certains critères de compatibilité. A chaque analyse, les méthodes les plus pertinentes sont sélectionnées selon les enjeux du territoire.

Ce cadre conceptuel a été appliqué à l'évaluation des effets de la principale filière avicole réunionnaise sur son territoire. Plusieurs scénarios d'amélioration et de croissance ont été explorés afin d'évaluer les perspectives de progression de la filière vers un état plus durable. Les effets de l'activité de la filière sur ses parties prenantes ont été calculés en mobilisant deux méthodes d'évaluation: l'analyse environnementale du cycle de vie et la méthode des effets. Les résultats montrent que les exploitations agricoles réunionnaises et la fourniture électrique sur l'île sont responsables de la majorité des impacts environnementaux sur le territoire. A l'échelle globale, ces impacts résultent avant tout des cultures de maïs, de soja et de riz et de la production d’électricité. Les impacts socio-économiques de la filière interviennent surtout sur le territoire grâce à un recours important aux services locaux hautement générateurs d’emplois et d’un soutien fort aux communautés rurales. L’analyse met en évidence les compromis qui doivent être faits entre réduction des impacts environnementaux et accroissement des bénéfices sociaux et économiques pour le territoire.

Le niveau de généricité du cadre conceptuel proposé a été évalué succinctement par rapport au mode d’organisation d’autres filières. Les filières agricoles prennent des formes très diverses dans le monde et l’on évalue aujourd’hui insuffisamment leurs effets sur les territoires. Une mise en œuvre systématique et généralisée du cadre conceptuel proposé pourrait y remédier.

Mots clés : Evaluation, Développement durable, Filière, Territoire, Parties prenantes, Volaille, La Réunion

Abstract

Increasing food security while respecting global ecosystems and human societies will be one of the major challenges of the coming decades. Agricultural supply chains are potentially powerful tools for rethinking production and food supply patterns. They are currently under pressure to include sustainability in their corporate strategy. In this context, both industry and policy makers require methods to systematically evaluate both the impact and the provision of services by supply chains to ecosystems and societies.

This thesis proposes a conceptual framework to measure the progress of a supply chain in terms of its contribution to the sustainable development of the territory in which it operates. The framework includes a strategic analysis of the territory for the collective identification of issues and possible measures for technical and organizational improvement. The framework encourages the quantification and spatial differentiation of effects with a view to inter-territorial equity. The different stakeholders involved, suppliers, competitors, the industrial environment and the community, should be included in the analysis. Applying strategic management theories, the number of stakeholders to include can be reduced to focus the analysis on the stakeholders that would be most affected by improvement measures. The framework can incorporate many available evaluation methods in the literature, such as life cycle assessment and the effects method, after some methodological adjustments. In each analysis, the most relevant methods are selected depending on the issues identified in the territory concerned.

The conceptual framework was used to assess the effects of the main poultry supply chain in Reunion Island. Several scenarios for improvement and growth were explored to assess the prospects for progress of the supply chain towards sustainability. The effects of the activities of the supply chain on its stakeholders were calculated using two assessment methods: environmental life cycle assessment and the effects method. The results showed that in Reunion Island, the farms and the electricity supply are responsible for the majority of environmental impacts at the territorial scale, while at the global scale, environmental impacts result primarily from the production of maize, soybean and rice and the supply of electricity. Most of the social-economic impacts of the supply chain occur within the territory, which relies heavily on services, generating local employment and strong support for rural communities. The results of the analysis also highlight the required trade-offs between

reducing environmental impacts and increasing the social and economic benefits of the supply chain.

The proposed conceptual framework remains to be thoroughly evaluated in other supply chains. Agricultural supply chains take very different forms in the world today and their effects on territories have not been sufficiently evaluated. The widespread implementation of a systematic conceptual framework could remedy this situation.

Keywords: Assessment, sustainable development, supply chain, territory, stakeholder, poultry, Reunion Island

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Introduction Générale

D'après les dernières estimations de l'ONU, la population mondiale atteindrait 9.6 milliards de personnes à l'horizon 2050 (Raftery *et al.*, 2012). Une partie de cet accroissement concernera les pays de l'OCDE, mais la majeure partie aura lieu dans les pays en voie de développement. En 2013, deux milliards de personnes, soit près du tiers de la population mondiale, souffraient d'une ou plusieurs carences en micronutriments (FAO, 2013).

En parallèle, le fonctionnement de la plupart des filières de production agricole est basé sur un système productiviste qui se définit comme « *la valorisation de la croissance de la production des marchandises pour elle-même, indépendamment des satisfactions des acteurs et des conséquences institutionnelles ou naturelles* » (Halbwachs, 1913). Autrement dit « *produire abondamment et à tout prix* » (Prével, 2008). Ce mode de fonctionnement, permis par l'utilisation d'engrais minéraux et de pesticides, l'amélioration génétique et les progrès technologiques de la mécanisation, connait déjà ses limites dans de nombreuses parties du globe à cause des problèmes environnementaux et sociaux qu'il engendre sur le long terme (Benhammou, 2009). Ils prennent des formes multiples à travers le monde depuis les plantations de coton transgénique impliquées dans l'appauvrissement des sols au Burkina Faso (Koné *et al.*, 2009) jusqu'aux élevages bovins brésiliens impliqués dans la déforestation de l'Amazonie (Fearnside, 2005). La France n'est pas épargnée par ces conséquences environnementales. On peut citer par exemple le modèle agricole breton qui depuis 20 ans joue un rôle important dans la pollution et l'eutrophisation de certains cours d'eau. La sécurité alimentaire est en passe de devenir le problème majeur de la prochaine décennie (Paillard *et al.*, 2010) alors que la durabilité des productions agricoles n'est encore qu'un objectif très lointain.

La demande en produit alimentaire est urgente, mais une façon plus durable de produire doit être repensée en conciliant l'environnement, l'homme et l'économie. Ce triptyque ou « *triple bottom line* » est l'approche incontournable pour opérationnaliser le concept de développement durable (UNCED, 1992b), du moins en théorie. Dans les faits, un grand nombre de disciplines se sont emparées de ce concept et l'ont façonné à leur manière et avec leurs objectifs (p.ex. économie, management stratégique, écologie). En résulte un concept élastique où la prise de décision est souvent limitée (Mebratu, 1998). De plus, de nombreux obstacles encore non résolues contribuent à laisser planer un doute sur la pertinence des évaluations de la durabilité. Par exemple, la construction d'indicateurs permettant d'évaluer ces trois dimensions de façon intégrée est toujours un challenge considérable (Morse *et al.*, 2001). Pourtant l'importance de cette intégration est non négligeable, car les solutions en termes de développement durable sont souvent le résultat d'un compromis entre plusieurs objectifs conflictuels (Roy and Vincke, 1989). L'absence de fonctionnement synchrone des indicateurs est donc clairement un frein à la prise de décision. De même, d'une situation à l'autre, d'un territoire à l'autre, l'évaluation de la durabilité peut aborder des échelles temporelles et spatiales différentes et impliquer des panels de parties prenantes différentes (van Zeijl-Rozema *et al.*, 2008). Par exemple, à l'échelle d'un territoire, la durabilité interne qui consiste à protéger son environnement direct et son cadre de vie, ne doit pas s'effectuer au détriment de territoires extérieurs par l'externalisation des problèmes (p.ex. transfert de pollution) (Zuindeau, 2002). La définition explicite des limites du système étudié reste cependant difficile à mettre en œuvre dans le cas de système complexe incluant par exemple les systèmes écologiques (Folke *et al.*, 2002). Enfin, appliqué aux productions agricoles, le challenge s'intensifie encore à cause de l'aspect multifonctionnel de l'agriculture. Les méthodes d'évaluation actuelles prennent généralement en compte les impacts de l'agriculture sur l'environnement, mais peu les évaluent conjointement avec les services rendus par l'agriculture à l'environnement (c.-à-d. les services environnementaux ; p. ex. la prime à l'herbe) et à la société (Millennium Ecosystem Assessment, 2005). Evaluer le durable en agriculture revient donc à évaluer une activité comprenant autant de modes d'organisation différents que de spécificités locales, tout en composant avec l'ensemble de ces dynamiques et de ces parties prenantes. Néanmoins, cette élasticité présente un formidable terrain pour le développement et l'innovation.

Bien que de nombreuses études abordent l'évaluation de la durabilité des filières de production agricole, peu d'approches permettent de prendre en compte cette complexité tout en fournissant une évaluation quantitative et pertinente pour les décideurs à la tête de ces filières. La plupart se focalisent sur les aspects environnementaux, très peu prennent en compte le double principe d'équité inter et intra-générationnelle (Bertrand Zuindeau, 2006) et aucune ne relie l'ensemble de ces éléments dans une évaluation cohérente et opérationnelle. L'absence de cadre conceptuel limite grandement la prise d'initiative et la responsabilisation des acteurs de la chaine de production. La demande pour ce type de travaux est urgente. Ils doivent cependant être conduits de manière à être assez générique pour être adaptés à un grand nombre de filières et de territoires, mais également assez concrète afin d'être opérationnels et utilisables par les acteurs concernés. La question centrale autour de laquelle s'est axé ce travail de thèse a donc été:

Comment évaluer la contribution d'une filière agricole au développement durable de son territoire?

Objectifs de recherche

Cette thèse sur convention CIFRE a été réalisée dans le cadre d'un partenariat tripartite entre:

- **Le CIRAD** (Centre de coopération internationale en recherche agronomique pour le développement). Les travaux se sont déroulés au sein de l'unité mixte de recherche SELMET (Systèmes d'élevage méditerranéens et tropicaux) et étaient positionnés sur le programme CIEEL à La Réunion (Conduite intégrée des exploitations et des filières d'élevage).
- **La société Crête d'Or Entreprise.** Les travaux étaient encadrés par le service Innovation et étaient positionnés sur le volet stratégique *développement durable* » de l'entreprise.
- **Le CEMOI** (Centre d'Economie et de Management de l'Océan Indien). Les travaux ont été menés sous la direction du professeur Yves Croissant.

Les objectifs de recherche de cette thèse étaient i) d'élaborer un cadre conceptuel permettant d'évaluer la contribution d'une filière de production agricole à la durabilité environnementale, sociale et économique de leur territoire, ii) de développer un outil de simulation spécifique permettant à la filière d'évaluer des stratégies encourageant un développement plus durable (projection de croissance et alternatives techniques).

Structure de la thèse

Le manuscrit est divisé en quatre chapitres précédés d'une introduction et terminés par une discussion générale. Cette structure est présentée dans la Figure 1.

Chapitre 1: Présentation d'un nouveau cadre conceptuel pour évaluer la contribution d'une filière agricole au développement durable de son territoire. Ce chapitre détaille les différentes références théoriques et méthodologiques étayant le cadre conceptuel, et présente un panel de méthodes d'évaluation mobilisables. Ce chapitre est en projet de soumission (en deux parties avec le chapitre 4) pour le *special volume:* « Embedding Sustainability Dynamics in Supply Chain Relationship Management and Governance Structures » de la revue *Journal of cleaner production*.

Chapitre 2: Evaluation environnementale de la filière avicole par utilisation de la méthode d'analyse de cycle de vie environnementale. Ce chapitre est publié sous forme d'un article dans la revue *Journal of cleaner production*.

Chapitre 3: Evaluation socio-économique de la filière avicole par la méthode des effets. Ce chapitre est en projet de soumission.

Les chapitres 2 et 3 présentent les résultats détaillés de l'application de deux méthodes d'évaluation sur le cas d'étude. Cette étape a pour objectif d'identifier les particularités de l'application de ces méthodes sur notre objet d'étude. Elle a également pour but d'évaluer la compatibilité de ces méthodes avec le cadre conceptuel et de dégager les éventuelles adaptations à réaliser en vue de les intégrer conjointement.

Chapitre 4: Application du nouveau cadre conceptuel sur la filière avicole réunionnaise. A partir des conclusions des deux chapitres précédents, le cadre conceptuel et les deux méthodes d'évaluation sont mis en œuvre sur la filière avicole réunionnaise en les couplant à plusieurs scénarios de croissance et de changement technique. Ce chapitre est en projet de soumission pour le même *special volume* de la revue *Journal of cleaner production*.

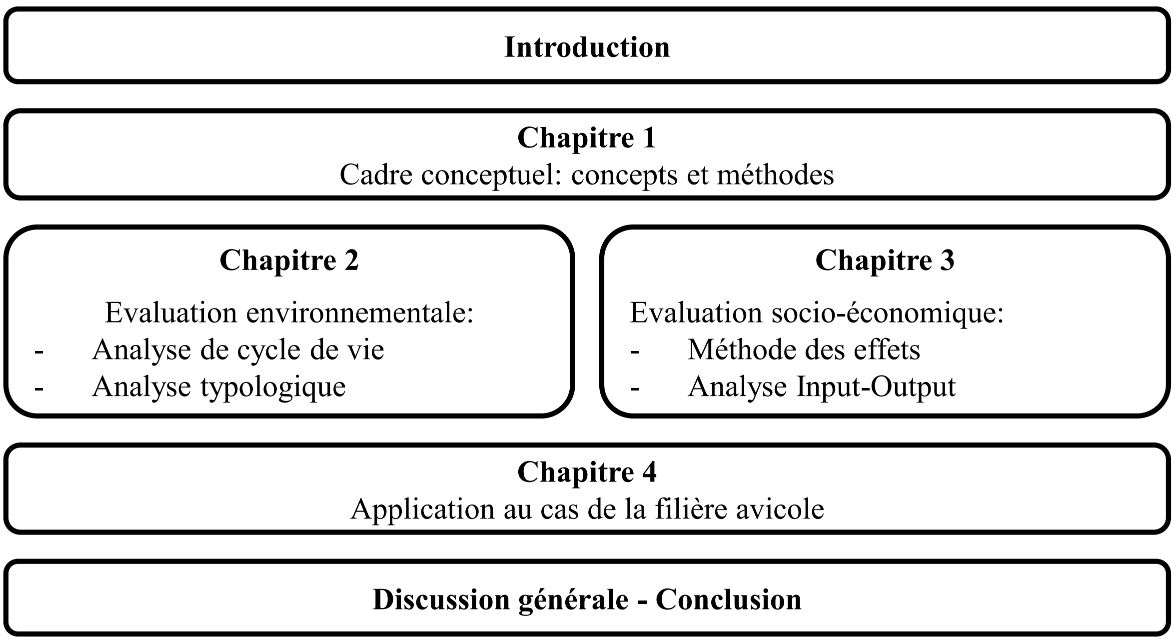

Figure 1: Structure du manuscrit

Terminologie

Les termes « Démarche scientifique », « Approche scientifique », « Cadre conceptuel » « Méthodologie », « Méthode », « Modèle », « Outil », et « Indicateur » sont utilisés à plusieurs reprises dans cette thèse. Ces termes peuvent des significations différentes en fonction du domaine scientifique (sciences formelles, naturelles, humaines et sociales) et de la langue (anglais ou français) dans lesquels ils sont employés. Leur signification dans cette thèse est présentée dans l'Appendice 1 : Terminologie.

Chapitre 1

Food chain sustainability assessment, Part I: a new transdisciplinary and operational framework

***Submitted** in Ecological economics*

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Abstract

Food chains face huge pressure to progress toward sustainability. The two main sustainability assessment approaches used today, neo-classical economics and eco-efficiency, have weaknesses that make them either ethically unacceptable, or inadequate to address the complexity and dynamics of the food chain. Both aim to maximize shareholders' interests and generally ignore equity, the main principle of sustainable development. Inspired by recent advances in several business theories and in sustainability science, this paper proposes a new framework to approach corporate sustainability from the stakeholders' point of view based on a transdisciplinary approach.

The framework was elaborated with holism and feasibility in mind. It first highlights the need to define a spatial scale in order to set boundaries for evaluating equity and efficacy, two components of the notion of sustainable development. To achieve a holistic representation, the system under study is defined as a social ecological system. Recent developments in stakeholder theory propose considering both social and environmental concerns as stakeholders (human and non-human stakeholders) thus reintroducing the two concerns as equal constraints in management activities. To achieve feasibility, the system boundaries are more clearly defined by selecting only the salient stakeholders of the social ecological system. The salience of the identified stakeholders is measured by the depth of their interactions with the food chain. In the proposed framework, the type of interaction and the cut-off criterion depend on the type of stakeholder. The participation of human stakeholders is of particular importance when defining issues at the scale of the territory and the corresponding indicators and assessment methods to be used to assess sustainability. As illustrations, we describe two methodologies for socio-economic and environmental impact assessment which fit the requirements of the framework particularly well. This paper discusses how the effective incorporation of concepts and methods from different disciplines (environmental sciences, economics, engineering science, etc.) is achieved by using the proposed framework.

Keyword: Sustainability science, food chain, transdisciplinarity, coupled systems approach, systems analysis

1. Introduction

1.1. Food chains in sustainability science

Research on food chain sustainability has increased considerably in the last ten years (Spangenberg, 2011). Food chains, or agricultural supply chains, are highly complex systems which it is essential to study in the field (Tilman, 1999). The choice of the method used to measure the progress of food chains towards sustainability is important because the majority of processes along the supply chain involve deep interdependences between nature and society. For instance, crop production, livestock breeding and rearing, which are the main stages in livestock supply chains, represent more than 90% of the total land use and generate 80% of the value-added of the supply chain. Each of these stages causes significant damage to nature through resources depletion (water, fossil, and mineral resources) and environmental degradation (land use change, loss of soil fertility, pollution) (Thévenot *et al.*, 2013a). In return, these interactions affect human activities in the form of declining yields, the risk of livestock-human related diseases, and water contamination (Liu *et al.*, 2007). On the other hand, food chains have positive effects on society, for instance by creating employment in rural areas (Thévenot *et al.*, 2013c). More broadly, the positive effects of food chains are generally included in the concept of agriculture multifunctionality (Cairol *et al.*, 2009; Huylenbroeck *et al.*, 2007; Renting *et al.*, 2009). They can be classified as four kinds of services. Yellow services support rural communities, territorial identity and development including the creation of employment. Green services support landscape management, biodiversity conservation, and wildlife preservation. Blue services concern water management in all its forms (quality, control, creation of energy). Finally, white functions concern food security and safety.

Whether the effects are negative or positive, the resulting consequences will vary in importance depending on where the effect occurs. For instance, nitrogen runoff from manure spreading may have a different effect on eutrophication depending on the frequency of rainfall in the region concerned. Manure may be considered as waste in areas with a structural surplus of nitrogen, or as a primary resource in developing countries where mineral fertilisers are expensive (Vayssières and Rufino, 2012). Changes in raw materials can have greater or lesser impacts on suppliers, depending on the extent to which the supplier depends on the activity of the supply chain. Access to a monopoly position can have greater or lesser impacts on a competitor, and indirectly on the community, depending on the structure of the competition. These examples show that a uniform and reproducible approach to evaluating food chain sustainability is neither possible nor recommendable. Sustainability assessment tools in food chain development planning are usually the same as corporate tools. Based on neo-classical economics (e.g. cost-benefit analysis) and eco-efficiency approaches (e.g. material flow analysis), the tools generally focus on productivity and efficiency, and do not satisfactorily account for the complexity of the above mentioned dynamics.

Neo-classical economics

Neo-classical economics was the first field to suggest assessing progress toward sustainability. The neo-classical model emerged in response to criticism of the classic model aimed at maximizing profits where the only limit was deception and fraud (Milton Friedman, 1962). The new model included a *moral minimum* criterion (Bowie, 1991) in the form of business responsibilities. Thus, the optimisation exercise has to deal with environmental constraints converted into monetary terms. However such conversions often underestimate basic ecological mechanisms because whenever monetary metrics cannot be assigned to an ecological function, this function is valued at zero (Hall *et al.*, 2001). This means many ecosystem services and environmental externalities are not taken into account (Gasparatos *et al.*, 2008) and large uncertainties invalidate optimisation results. Finally these weaknesses maximize the interests of corporate shareholders rather than those of nature and society. For these reasons, neo-classical economics has been widely criticised on ethical grounds and considered as weak sustainability (Pearce and Atkinson, 1993).

Eco-efficiency

Another approach widely used to deal with sustainability at corporate level is eco-efficiency. Popularised by the World Commission on Environment and Development (WCED) (Stigson, 2000), broadly, eco-efficiency means to "do more with less". The WCED definition of eco-efficiency is *"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity"*. This definition is interpreted in different ways by practitioners (Perron *et al.*, 2006). The guidelines developed so far generally focus on resources efficiency, waste, and pollution intensity but ignore other aspects of the definition. Eco-efficiency is usually implemented from a life cycle perspective and was developed with the primary objective of genericity. This primary objective now appears to be slowing down its integrative development in the three dimensions of sustainable development because of its dependence on the contextualisation of social stakes (Kloepffer, 2008; Reap *et al.*, 2008) and hence the difficulty in identifying pathways between a firm and its social impacts (Feschet *et al.*, 2013). Moreover, eco-efficiency is usually in the hands of the focal firm which is subject to stakeholder pressure for sustainable development (Kovacs, 2008). For these reasons, eco-efficiency is considered to be a valuable but insufficient concept for the assessment of corporate sustainability (Dyllick and Hockerts, 2002).

In a recent review, Brandt *et al.* (2013) state that *"attempts to meet the demands of the current generation without compromising the ability of future generations to meet their own needs, the essence of sustainable development, remains at best a distant goal".* This failure in the underlying ethical principle of this definition, intergenerational equity, can easily be extended to intragenerational equity. In fact, the claim of the former has often been at the expense of the latter (Beder, 2000; Hahn *et al.*, 2010). Intragenerational equity is about fairness i.e. access to similar rights, opportunities, and all forms of community capital among communities. However, the two previously mentioned approaches to sustainability assessment have been accused not only of reinforcing inequities between communities but also of creating new ones. These serious weaknesses exist because at their current stage of development, none of the approaches successfully accounts for both agriculture multifunctionality and sustainable development challenges in a coherent framework.

1.2. Need for a new framework

Recent paradigm shifts and developments in corporate management theory and sustainability science suggest promising new ways to deal with these obstacles in the future. First, recent developments in coupled social-ecological systems applied to corporate and food chains provide a useful framework to capture the above-mentioned reciprocal effects but call for a transdisciplinary approach rarely seen in management (Porter and Derry, 2012). Second, the need to include components of the natural environment such as non-human-stakeholders has been raised by several authors to overcome the lack of empowerment of nature in management practices (Kjell Tryggestad *et al.*, 2013; Norton, 2007; Starik, 1995). Third, recent attempts to transform planetary boundaries into non-human stakeholders described by (Rockstrom *et al.*, 2009) should make it easier to address environmental constraints in models (Whiteman *et al.*, 2013). And finally, stakeholder theory has moved away from the shareholder wealth maximization paradigm in neo-classical economics by focusing on wider external stakeholders' interests (Ayuso *et al.*, 2012; Loorbach and Wijsman, 2013). Even if these fundamental transitions are still under discussion and sometimes disputed, they offer great opportunities for conceptualisation in a new transdisciplinary framework.

In sustainability science, transdisciplinary research is recognized as being useful to structure theories and problems in a collaborative learning process (Shrivastava *et al.*, 2013; Schaltegger *et al.*, 2013). The ideal-typical process of transdisciplinarity research was suggested by (Lang *et al.*, 2012) to have three stages: 1) Collaborative problem framing, which focuses on societal and real world problems; 2) the co-creation of a problem oriented solution, which enables a mutual learning process among researchers from different disciplines and non-scholars; 3) The incorporation and application of the knowledge produced, with the aim of transferring the knowledge to both scientific and societal practice.

This paper is Part I of a two-part a series. It focuses on points 1 and 2, and describes a new conceptual framework based on the recent above mentioned developments. The main goals of this framework are to pertinently link supply chain management leverages with the real sustainability stakes of a given socio-ecological system, and to operationalize the establishment of improvement scenarios along a food chain to improve its contribution to sustainable development. The second paper (Part II) describes an application of the proposed framework corresponding to point 3.

2. Principles of the approach

Figure 2 shows the multiple interactions between a food chain and its environment using the proposed framework. The food chain interacts with stakeholders from nature and society. Consequently, we represent the food chain as a network which coevolves within a social subsystem and interacts with an ecological subsystem (the bottom part of Figure 2) (Loorbach *et al.*, 2010; Porter, 2006), both embedded in the Earth system at given spatial scales (i.e. territorial versus global). The food chain activities may negatively or positively affect i) humans, as living beings, and non-human stakeholders of ecological subsystems through direct interactions with resources or indirect interactions with planet boundaries; ii) human (as a social entity) stakeholders of social subsystems in the strategic environment of the food chain (competitors, suppliers and supply chain actors) or in the community also through direct or indirect interactions. All these interactions are represented by the arrows in Figure 2. These direct or indirect interactions can take place within this social-ecological system and at global scale in other social-ecological systems (i.e. outside the territory).

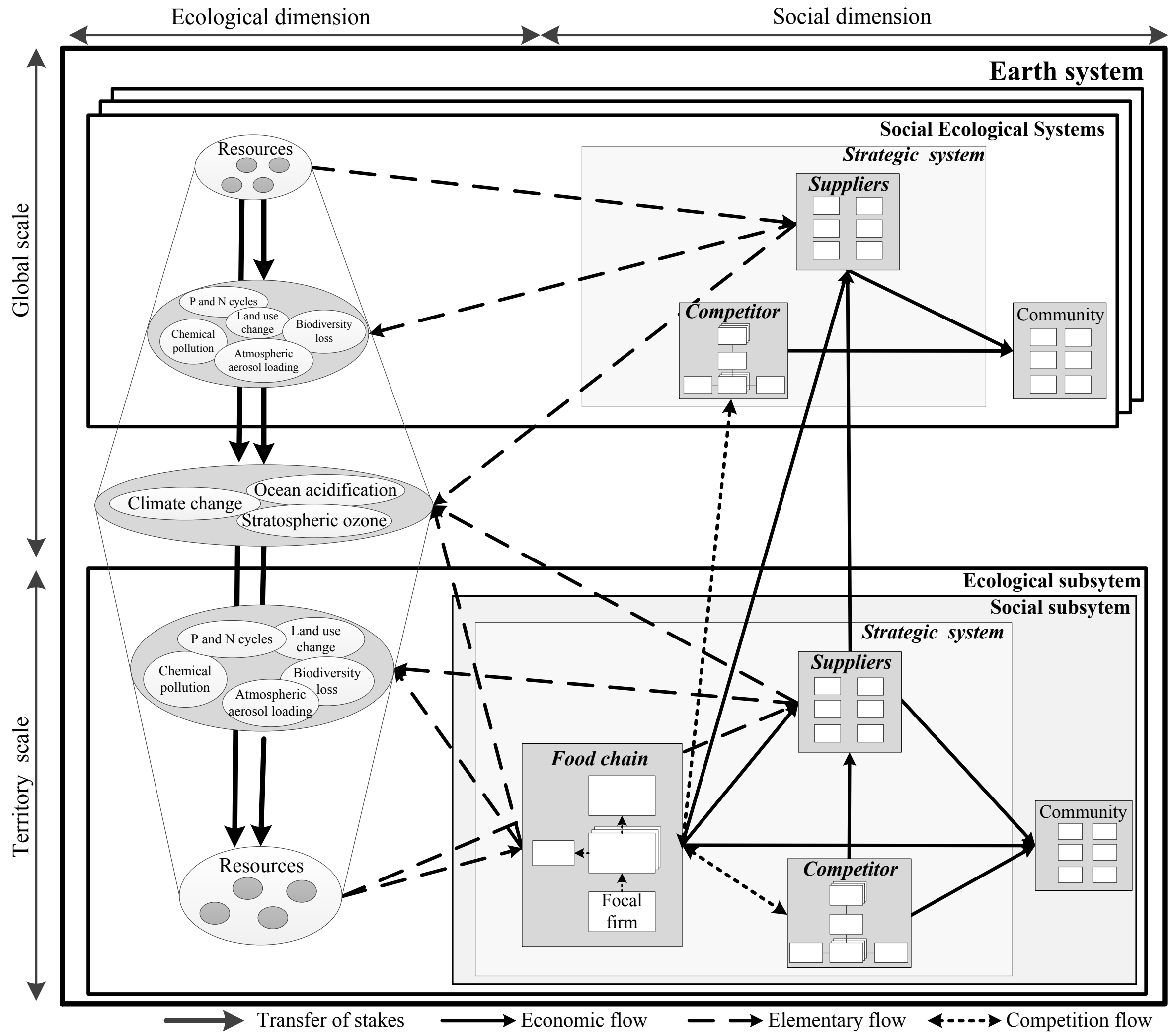

Figure 2: Multiple interactions between a food chain and its environment across different scales and dimensions.

Figure 3 shows the procedure used to analyse the multiple effects of a food chain. Analysing such complex systems (see Figure 2) requires being selective. (1) First, from a geographical point of view, differentiating the scale of the territory from the global scale and (2) identifying the pool of stakeholders. Then, following a systemic approach, depicting the social ecological system in which the supply chain is embedded. (3) The system boundaries are drawn so as to include only those stakeholders of the social ecological system who have strong interactions with the food chain (Eakin and Luers, 2006). These stakeholders are selected with a cut off criterion based on the degree of their interactions. (4) A dynamic assessment of the system is required to evaluate the progress of the food chain toward sustainability. Scenarios are designed to enable a dynamic comparison of the state of the system at different times, completed by a consequential analysis. A change in activities could mean mitigation measures (e.g. change in processes, suppliers, and raw materials) and changes in production outputs (types, volumes). Then, in accordance with steps 3 and 4, indicators and methods are selected and applied (5).

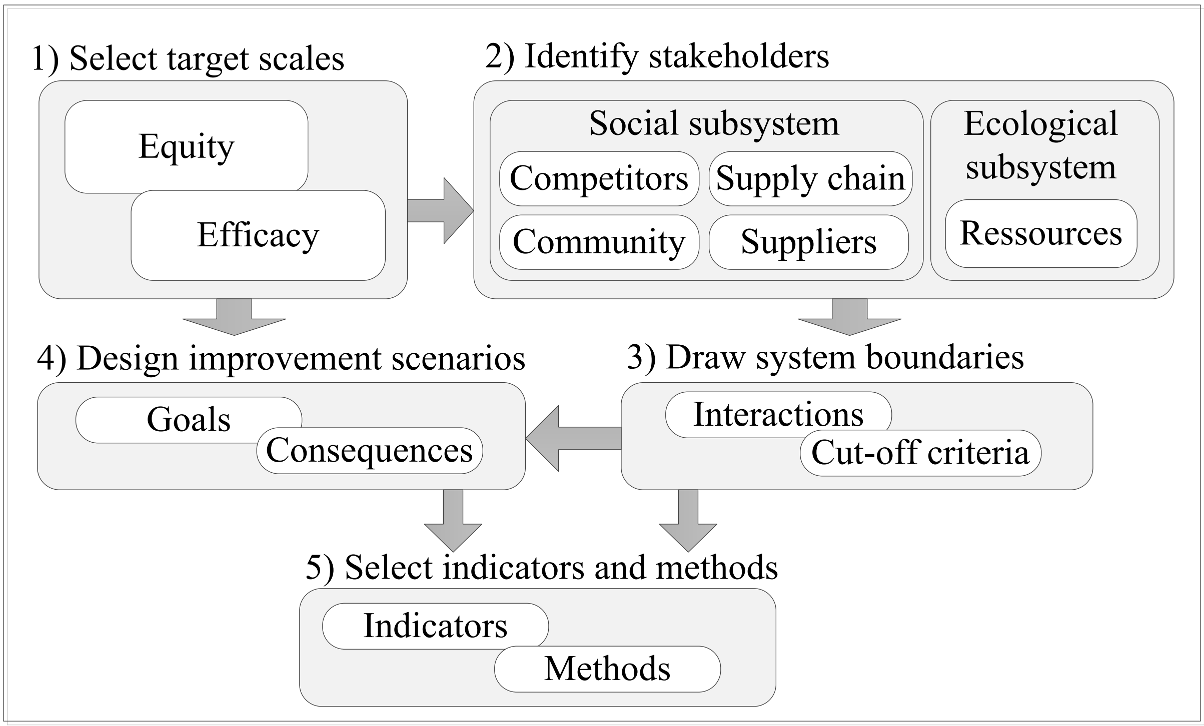

Figure 3: Five steps procedure used to analyse the multiple effects of food chains

The analysis of existing interactions in such complex systems has often led to sustainable development being considered *"either from the angle of an ecological system subject to anthropic disturbance or, alternatively, from the angle of a social system subject to natural constraints"* (Bousquet *et al.*, 1999). A transdisciplinary approach is recommended to obtain a more holistic representation of these interactions and their dynamics (Kates *et al.*, 2001). Such an approach places importance on the participation of non-scientists in the analysis. Stakeholder participation has proven to be a determining factor in improving the quality of knowledge of the system concerned, by facilitating the co-generation of knowledge, increasing trust, ownership of results and empowerment of solutions, and in facilitating problem solving (Sala *et al.*, 2012). In fact, now more than ever, stakeholders are demanding to be heard, and listening is a vital target with respect to the performance and attractiveness of a firm (Dubigeon, 2005).

Several approaches exist to include stakeholders in the knowledge building process (Walker *et al.*, 2002). One of these, the companion modelling approach (ComMod, 2005), is a participatory approach that rightly aims at combining social and environmental dynamics in an iterative procedure to solve problems affecting complex social-ecological systems

(Barnaud and Van Paassen, 2013). Figure 4 shows how a transdisciplinary approach can be used to assess the sustainability of the food chain. The spiral formalises the iterative aspect of the approach. Each loop of the spiral corresponds to an iteration of the five-step procedure shown in Figure 3. The initial analysis, corresponding to the first iteration of the five-step procedure, can be conducted using a top down approach in which the identification of scales, system boundaries, stakeholders, indicators and methods are derived from sustainability principles by the researchers concerned (Binder *et al.*, 2010). An ongoing evaluation is then undertaken using a bottom up approach by asking the stakeholders how they perceive the first theoretical considerations. The reflexive analysis requires several iterations (i.e. loops) to reach consensus on the best conceptual construction to evaluate the sustainability of the food chain.

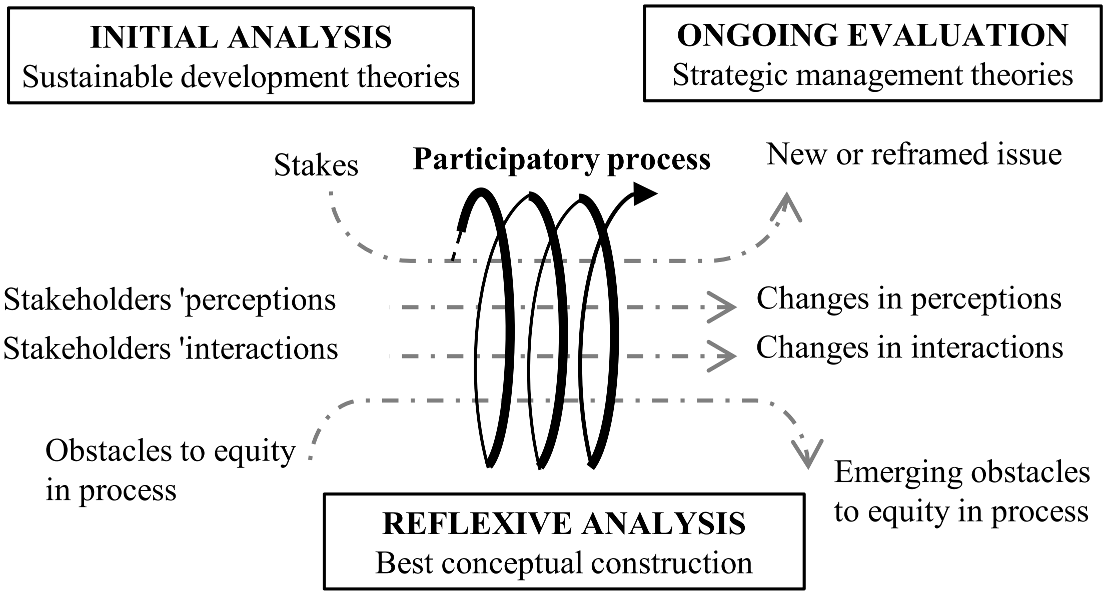

Figure 4: A transdisciplinary iterative approach for the assessment of food chain sustainability (adapted from Barnaud and Van Paassen (2013))

3. From the spatial scale of evaluation to the stakes

A geographical approach is increasingly being applied in sustainability science in particular to address the challenges of equity and efficacy (B. Zuindeau, 2006; Nijkamp *et al.*, 1991). The most recent and widely accepted definition of scale in sustainability science is that of Cash *et al.* (2006) who define *"scale" as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and "levels" as the units of analysis that are located at different positions on a scale"*. The term 'territory' corresponds to a geographical area that seeks to aggregate intrinsic specificities at a certain scale to justify its uniqueness.

According to Laganier Richard *et al.* (2002), these specificities can be classified in three dimensions. The identitarian dimension is characterised by a name, a history, and the way social groups live. The material dimension is characterised as a 'scape' with natural properties which define its potentiality and constraints to its development, and the renewable and non-renewable material properties resulting from land use. The organisational dimension is characterised as an entity with an organisational pattern between social and institutional actors. Thus, the territory scale does not refer to a local, regional, or national level but rather seeks to establish a level that can be differentiated from the global level (Laganier Richard *et al.*, 2002). This differentiation is needed in the framework to grasp the extent to which equity has been achieved between territories. Indeed, according to sustainable development principles, internal sustainability, which consists in sustaining its direct social and ecological environments, should not be acquired at the expense of external sustainability (global) by externalising problems on other territories (Pollution Haven Hypothesis) (Liddle, 2001). However, given the heterogeneity between territories, it is unlikely that each local system could reach a sustainable state on its own (B. Zuindeau, 2006). Godard (1996) stated that equilibrium can be found at global scale with local damaged or unbalanced territories. This does not rule out the fact that the externalities which cross the territory boundary have to be monitored if they are to be minimised or handled in a more sustainable way. Another challenge of this differentiation is efficacy, first mentioned by Camagni *et al.* (1998) and subsequently discussed by B. Zuindeau (2006). This approach, which is based on the theory of 'fiscal federalism', emphasises several advantages of decentralised action. The two main advantages are, first, decentralised action more clearly distinguishes between stakeholders who affect and stakeholders who are affected and consequently adapts the strategic goals of the food chain to the stakes of the territory. Second, the approach makes it possible to link global goals and local actions, which is crucial for progress (Kates, 2012). The geographical approach to the territory can include all types of entities (e.g. social groups, humans, resources, animals) in the problem framing, although not all of them are linked with the food chain, and even fewer are relevant for the analysis of food chain sustainability. One way to approach these entities in corporate management is through stakeholder theory.

4. Identifying stakeholders

In his seminal work on stakeholder theory Freeman (1984, p.46) defines stakeholders "as any group or individual who can affect organisation objectives or is affected by the achievement of organisation objectives" (Freeman, 1984). Originally, this concept was developed to address relationships between the firm and groups that might put pressure on the firm's objectives. This definition was flexible enough to include any groups with a close or more distant relationship with the firm. Consequently, it was narrowed to only include relationships based on resource dependence, power and risk in order to set up preferential treatment among them with the aim of establishing a hierarchy (Driscoll and Starik, 2004). Later, it was further expanded by the "Corporate Social Responsibility" debate to include broader society, but the question of the meaning of "can affect" and "can be affected" still limits companies in the choice of the effects to be taken into consideration (Lopez-De-Pedro and Rimbau-Gilabert, 2012). In practice, stakeholder management was still used in a "corporate-centric" way with a limited number of groups, most of whom were shareholders (Steurer *et al.*, 2005). Several authors moved away from this tendency to investigate the definition from a stakeholder perspective. The relationship between the company and stakeholders was enhanced by power, legitimacy and urgency attributes to identify only who or what really count (Mitchell *et al.*, 1997). The stakeholders' salience was assumed to depend very much on the strength and on the combination of those attributes in each stakeholder group. The number of groups changed frequently during the development of stakeholder theory. At first, Freeman (1984) identified eleven social groups of potential stakeholders for the firm who might be in the strategic environment of the firm, for instance employees, suppliers, but also part of the wider community, including the media, environmentalists, and local organisations. Many rearrangements have been made since, but the most noticeable addition is the inclusion of nature as a non-human stakeholder (Norton, 2007; Starik, 1995; Mishra and Suar, 2013). This consideration is still being debated (Phillips and Reichart, 2000) but has the merit of reintroducing nature in management considerations when it comes to trade-offs. If we review what is currently considered to be a salient stakeholder from the point of view of sustainability, we can divide groups into several categories depending on whether they share economic flows with the supply chain as employees, customers, or suppliers (Porter and Derry, 2012), or have non-market relationships as communities, competitors, or associations, or material flows as the environment and living beings. In the following, we provide a non-exhaustive review of useful concepts to identify different types of salient stakeholders related to supply chain activities.

4.1. Stakeholders of the social subsystem

Vertically organised in the past, food chains have adapted to the global crisis by organising new actors based on coordination and integration. At each link, the vertical development of the supply chain is enhanced in the horizontal dimension and emerges as a network production structure. A network is an efficient way to deal with the organisational complexity of the social environment of the supply chain (Miles and Snow, 1986). The identification of certain types of stakeholders related to supply chain activities could be tackled using recent applications of game theory in the field of social life cycle assessment. According to Swarr (2009), externalities represent a zone of conflict between the company and society. Drawing the boundary of this zone makes it possible to determine which actors are inside the zone and how they will be affected. To identify these actors, Lagarde and Macombe (2013) suggest using a systematic competitive model derived from the combination of the value net model and the strategic arena (Bidault, 1988; Rothschild, 1984). The strategic arena is delimited by all the firms who contribute to satisfying the same elementary need. Thus the arena includes all the competing firms who provide products with the same function on the same market, but also all the firms who provide the goods and services required for these activities i.e. suppliers. The substitutability between food chain productions can vary in extent, and can depend on consumers' regional preferences or religious belief. For example, whether poultry and pork are in competition varies considerably north and south of the Mediterranean Sea. The participation of the stakeholders is consequently a necessity at this step. The importance of our framework is that it reveals unexpected interdependences between competitors with respect to their suppliers. In small territories, the decisions made by a firm in a monopoly situation can have an unintended cascading effect on both suppliers and on the community. Five categories of stakeholders may be affected by the decision-making process of the supply chain: the focal company, collaborators, suppliers, competitors, and communities. The type of relationship between food chains and these stakeholders depends on the type of stakeholder involved. The focal company, the collaborators, the suppliers, and the local community may be affected through the economic flows they share directly or indirectly. The competitors may be mainly affected by the loss or gain of market share. And the community may be affected by the loss of value of each previously mentioned stakeholder.

4.2. Stakeholders of the ecological subsystem

Investing in environmental assessment is now a routine part of business management. With the growing demand for corporate social responsibility, many methodologies and tools have emerged, the most common being material flow analysis, life cycle assessment, environmental impact assessment (Finnveden and Moberg, 2005). These methods can characterise a large set of environmental impacts. Characterisation factors make it possible to identify pathways between substances consumed and emitted by the environment, and safeguard subjects. Safeguard subjects are elements of the natural environment which are considered to be intrinsically worth protecting (Beltrani, 1997). The safeguard subject category comprises natural resources, human life, natural environmental quality and manmade environments (Bare and Gloria, 2008). However, the choice of safeguard subjects and weighting methods between impacts have always been controversial and an obstacle to improvement because of the subjectivity of the process itself, which depends to a great extent on the type of stakeholders involved (Soares *et al.*, 2006).

Another way of approaching environmental issues recently emerged through the concept of planetary boundaries. Rockstrom *et al.* (2009) describe nine boundaries for the planet with associated thresholds which human intervention must not exceed. They define a “safe operating space” for human activities based on the pollution assimilation and resources regeneration capacities of the environment. These boundaries include climate change, ocean acidification, stratospheric ozone, the biochemical nitrogen and phosphorus cycle, global freshwater use, land use change, loss of biodiversity, chemical pollution and atmospheric aerosol loading. The authors claim that seven of the nine boundaries have been quantified and three have already been transgressed by human intervention. Several first attempts to link the management scale to the safe operating space of these *planetary boundaries* have emerged from this approach (Whiteman *et al.*, 2013). The adaptation of these planetary boundaries to subscales is still in its infancy but provides promising insights for the development of a safe corporate operating space. According to Whiteman *et al.* (2013), this framework may be useful to move from assessing corporate behaviour to assessing corporate participation in the decline of the Earth system. Recent developments in stakeholder theory suggest that safeguard subjects should be assimilated as non-human stakeholders in corporate management. This shift in thinking should enable a real empowerment toward sustainability rather than just a focus on economic interests and some efforts towards environmental efficiency. Food chains are involved in approaching all nine boundary thresholds in many ways (see section 1).

5. Drawing system boundaries: identifying interactions and cut-off criteria

From a management point of view, the multiplicity of interactions between stakeholders and food chains is an obstacle to operationality and calls for more selectivity. Moreover, all interactions are not quantitatively and/or qualitatively relevant and are therefore not significant for the outcome of the analysis. There are many different types of human and non-human stakeholders related to the supply chain in the social and the ecological subsystems and many ways to affect these stakeholders. The present overview is consequently not intended to be exhaustive. In the following, we suggest the use of several methods to select salient stakeholders based on the degree of interaction between each stakeholder and the food chain. Concerning the social subsystem, the different types of interactions are identified using business management concepts. Here we highlight the use of the 'value-added' construct to calculate the effects that affect or improve stakeholders of the social subsystem. This construct has the advantage of being operationalisable, measurable, and based on available data (Pitelis, 2013). We agree that the nature of companies' relationships with stakeholders goes far beyond these metrics. For instance, relationships of confidence, moral prejudice, loyalty, security, quality have been documented in the field of sustainable corporate development. However given that the aim of our framework is to provide quantitative indicators and to account for trade-offs between them, we only focus on the derivation of existent metrics. Concerning the ecological subsystem, the different types of interactions are identified from environmental engineering and ecology concepts.

5.1. Interaction with suppliers

Buyer-supplier relationships have been widely investigated and characterised in strategic management (de Boer *et al.*, 2001). Resource dependency theory is a particularly useful concept to limit asymmetric interdependency between firms and their resource suppliers using mergers, acquisitions, or joint ventures, for instance (Pfeffer and Salancik, 1978; Hillman *et al.*, 2009). This relation of power could be reconsidered from a social point of view where the greater the interdependence, the more the focal firm's decisions can affect its suppliers. One indicator used in competition law to prevent abuse due to economic dependency is the economic dependency rate of the supplier. This rate is the percentage of a supplier's total turnover in contract with his buyer. Although this rate does not satisfactorily describe the buyer-supplier relationship, it is sufficient to be used as a threshold criterion to classify suppliers according to the effect the focal firm may have on them. The degree of substitutability of the supplier and the degree of coordination between the buyer and the supplier are generally correlated with this rate (Boons *et al.*, 2012). Three types of suppliers can be identified with respect to this rate. The first type is collaborators who are closely linked to the focal company by complex coordination mechanisms and are not substitutable. The focal firm and its collaborators are what is usually described as '*the food chain*'. The second type is the first-tier suppliers, who develop coordination mechanisms with the focal company. Their activity depends to a great extent on the activity of the focal company but they are substitutable. The third type comprises the remaining suppliers, who have a loose relationship with the focal company and are substitutable. In this paper, we use the name 'supply chain industrial network' to describe the food chain and its first-tier suppliers

5.2. Interaction with competitors

Relationships between competitors can be described through the competitive advantage each would have by acquiring a larger market share. Even if the gain in market shares follows the competition law, it may still affect one or several competitors and should therefore be taken into account in assessing sustainability. In the long term, competition on small local markets may affect competitors directly, and shared suppliers and the local community indirectly. The competitive environment deduced from the analysis of the social subsystem undertaken in section 4.1 provides the basis for identifying competitors on the target market. The market size should then be evaluated using classic market sizing top down and/or bottom up approaches. Food consumption surveys are useful, because they have the advantage of being quantitative and well documented. Approaches undertaken at territory scale should also make it possible to create cut-off criteria based on vulnerability to market share losses by identifying the turnover and production thresholds of competitors. The potential future market share gains or losses of salient competitors are included in the framework as an exogenous variable which affects the productivity of the supply chain.

5.3. Interaction with the community

The supply chain interacts with the community in various ways, the two most important being the share in value-added and the impact on human health. First, a firm does not act on its own. In agro-industrial activities, collaborators and first-tier suppliers are generally located close to one another. The employees of this cluster of firms are integrated in the surrounding community, which provides basic infrastructure and services (e.g. health care services, schools, grocery stores, banks) (Lund, 2012). In rural areas, where parts of food chain activities usually take place, the surrounding community ensures the stability and social cohesion of local society, which are indispensable for the firm's long-term prospects. This is the concept that Porter and Kramer developed through the principle of *creating shared value* (Porter and Kramer, 2011). Integrating society's economic and societal prosperity is now seen as a long term positive investment which provides a competitive advantage. Supply chain activities generate direct value added, which is divided between wages, taxes and capital, but also indirect value-added through its suppliers, and results in value-added through its own employees and the employees of its suppliers. However, the community is also the first speaking entity affected by the different types of pollution caused by the supply chain. Such pollution can have a direct impact on human health through emissions into the air (e.g., particulate matter), into the soil and water (e.g. chemicals and fertilizer runoff) but also through noise and unpleasant odours.

5.4. Interactions with the environment classified as non-human stakeholders

Food chains interact with the ecological subsystem through elementary flows which affect planetary boundaries (see section 4.2). Elementary flows are energy or matter which enter or leave the study system and are extracted from the environment without human transformation, or are emitted or discarded into the environment (Guinée *et al.*, 2002). Consumption and disposal are generally site specific or site dependent, whereas emissions can occur into the soil, water, or air and their impact thus ranges from site specific to global. Characterisation methods have been developed mostly in the field of life cycle assessment in order to link and aggregate substances with their impacts on planet boundaries and human health. For a review of the most common methods and impacts see Pennington *et al.* (2004). Flows or activities that are not relevant are excluded using a cut off criterion based on their relevance expressed as a percentage of total environmental impacts. Given the importance of using a participatory approach in sustainability science, we previously underlined the need to establish a hierarchy between the pathways which affect these boundaries using a panel approach in which different elicitation procedures are applied to get the panel members to provide weighting factors (Ahlroth *et al.*, 2011). The subjective aspect of the reasoning is therefore accepted at this point but should be overcome by further research.

5.5. Feedback loops

The medium to long-term sustainability of a social-ecological system depends on feedback mechanisms. Feedback is defined as *"an influence or message that conveys information about the outcome of a process or activity back to its source"* (Capra, 1996) or according to Sundkvist *et al.* (2005) when a "system component can itself be influenced indirectly by the changes it has induced". In the ecological subsystem, regulating ecosystem services (e.g. the hydrological cycle, biodiversity, soil resources) include feedback mechanisms which enable the resilience of the whole system (Cabell and Oelofse, 2012). Some agricultural supply chain activities rely on the existence of such services (e.g. crop production, animal breeding). By spoiling their functioning, mostly through the release of chemical pollutants (e.g. loss of biodiversity, polluted soil and water), poor agricultural practices reduce crop yield, increase animal diseases etc. and thus affect supply chain efficiency (Clancy, 2013)**.**

6. Temporal scale and scenarios

A dynamic approach to food chain sustainability is needed (Atkinson, 2000). Firstly, a static view cannot assess progress so the relevance of mitigation measures and their consequences for potential new stakeholders cannot be investigated. Secondly, a static view cannot account for reciprocal effects or other interactions such as competition. An improvement in corporate sustainability measured by a dynamic analysis can be defined as progress from weak sustainability to strong sustainability (Figge and Hahn, 2004). Weak sustainability is defined as the possibility to exchange manmade or human capital for natural capital, and "ecological economists use the biophysical limits of the earth as the starting point" (Pearce and Atkinson, 1993). The European Union's emissions trading scheme is a well-known example of the failure of this system (Andrew, 2008). Strong sustainability does not allow such exchanges. Balanced sustainability assumes flexible economic – environmental exchanges with respect to critical natural stocks (Hueting and Reijnders, 1998).

Opening up to allow a dynamic approach to the system combined with a transdisciplinary approach also makes it possible to analyse the consequences of improvement measures. It has already been shown that solutions which were identified without taking into account the whole system, in which the system is embedded, may damage rather than improve the system. A historic example is the adverse effects of the increasing demand for biofuel as an alternative to petroleum. First, from an ecological point of view, it has increased the carbon debt because of the change in land use from rainforests and grasslands to croplands (Fargione *et al.*, 2008; Searchinger *et al.*, 2008) and from the social point of view, it has increased poverty and hunger in developing countries by increasing the price of cereals on the world market (de Gorter and Just, 2010; Hall *et al.*, 2009). This shows that the potential consequences of the decision must be included in the ex-ante evaluation of projects. One way to assess the consequences of possible solutions consists in including all alternative products to the outputs of the system under study. This step involves a search for processes which could be affected by supply chain processes. According to (Weidema *et al.*, 1999), an affected process is a process which is not subject to constraints in its production capacity and responds to a slight variation in the demand for the product resulting from this process. Consequential analysis thus makes it possible to measure positive or negative effects between actors and the supply chain by identifying the time horizon of the change, market limits, market volume trends, and differences between supply and demand (Weidema *et al.*, 2009).

7. Indicators and assessment methods

The procedure described above seeks to embed the food chain to be assessed in an analytical framework in which the food chain will be evaluated on the basis of its interactions with stakeholders of the social-ecological system. To perform a quantitative assessment, indicators and assessment tools which are compatible with this framework should be selected with reference to the most important stakes.

7.1. Potentially useful tools

A large number of indicators, indices, methods and tools to assess sustainability can be found in the literature (Singh *et al.*, 2012; Thévenot and Vayssières, 2011; Aubin *et al.*, 2011; Ness *et al.*, 2007). The framework we provide is flexible enough to allow the incorporation of a range of calculation methods as long as they ascribe to the principles we describe above. First, the calculation procedure is open to spatial discrimination of inputs and outputs in order to handle externalities. Second, the calculation procedure is based on the strength of the relationship between the stakeholders and the food chain.

In the following, we describe two classical methods that are particularly useful for the assessment of two major stakes faced by most agro-industrial food chains: employment and environmental impacts. The proposed methods are an alternative use of a cost-benefit analysis, the effect method (Chervel and Le Gall, 1989), and environmental life cycle assessment (Guinée *et al.*, 2002). They have already been used separately in previous studies conducted by our team (Thévenot *et al.*, 2013a; Thévenot *et al.*, 2013b) and are now being used in the same system assessment approach with reference to a common framework.

7.2. Socio-economic indicators and methodologies

The effect method developed by Chervel and Le Gall (1976) is a cost benefit analysis which uses input-output analysis for project appraisal. This method is particularly useful because it supports micro- and macro-economic goals. Based on the value-added generated by the project, it is possible to characterise the redistribution of wealth to the supply chain, suppliers, and, in a second phase, to the community. When input-output tables are available, it is also possible to regionalise wealth distribution by adding a variable on localisation (Miller and Blair, 2009). Wealth can then be translated into jobs, tax and capital, which then makes it possible to assess job creation (Thévenot *et al.*, 2013b).

7.3. Environmental indicators and methodologies

Environmental life cycle assessment emerged from engineering science and has proved to be a useful tool for the management of eco-efficiency of supply chains. Environmental life cycle assessment has distinguished itself in a rich literature by its capacity to provide a holistic assessment. In classical life cycle assessment, assessed sources and receiving environments are site-generic. Recent developments in spatial differentiation in life cycle assessment should now make it possible to spatially differentiate characterisation and exposure factors according site dependant or site specific levels (Potting and Hauschild, 2006). Some regional LCA studies have investigated the inventory phase (Bourgault *et al.*, 2012; Mutel and Hellweg, 2009) as well as some impact categories including the impact of air pollution (Tessum *et al.*, 2012), and of land use on ecosystem services like the provision of freshwater (Saad *et al.*, 2013), and biodiversity (de Baan *et al.*, 2013). However, the genericity of calculated impacts tends to keep managers ignorant of the real impacts of their firm's activities. The geographic interpretation of results should make it possible to translate planetary boundaries into territory scale boundaries and therefore clearly link these boundaries with the management scale.

8. Transdisciplinarity and integration - achievements

The goal of this paper is to present a framework linking supply chain management leverages with the real sustainability stakes of a given socio-ecological system, and to operationalise the establishment of improvement scenarios along a food chain to improve its contribution to sustainable development. In section 1.2, we underlined the importance of using an integrated and transdisciplinary framework.

8.1. Transdisciplinarity

First, for transdisciplinarity to be achieved, concepts from different disciplinary fields of science have to be gathered together in a framework which is jointly and iteratively developed in collaboration with a wide range of stakeholders.

The conceptual framework proposed here was elaborated with reference to numerous concepts and methods from natural, social, and formal sciences. The main concepts and methods in the proposed framework and their origin are listed in Table 1.

Table 1: Classification of main concepts and methods referred to in the proposed framework and the scientific fields in which they originated

	Natural science	Social science	Formal science
Neoclassical economics		X	
Eco-efficiency	X		X
Coupled systems theory	X	X	X
Companion modelling approach		X	
Scale	X	X	
Stakeholder theory		X	
Value net model		X	
Strategic arena		X	
Planetary boundaries	X		
Resource dependence theory		X	
Competitive advantage theory		X	
Creating shared value		X	
Consequential analysis		X	
Environmental Life cycle assessment	X		X
Effect method		X	X

The coupled system theory, which is used in all branches of science, provides the appropriate analytical framework to depict interdependences between the social and the natural subsystem (see Figure 2). The concept of scale largely developed in human and physical geography is particularly useful to tackle equity and efficacy, two fundamental principles of sustainable development (see section 3). Several theories that emerged from social sciences, more precisely from business studies, are useful to show how the food chain is embedded in a social subsystem by characterising the relationships between actors (see section 4.1). These theories include the stakeholder, the resource dependence and the competitive advantage theories. The stakeholder theory makes it possible to identify stakeholders among the different entities of the social-ecological system. Resource dependence theory helps select only the salient suppliers. Competitive advantage theory makes it possible to select only salient competitors and the creating shared value concept makes it possible to take the community into account. Finally, environmental and economic methods (e.g. environmental life cycle analysis, input-output methods) from applied science have been used to calculate the most important indicators with reference to the most relevant stakes. This use of different disciplines can lead to different degrees of integration, usually classified in three groups: multidisciplinarity, interdisciplinarity and transdisciplinarity (Morillo *et al.*, 2003). Multidisciplinary looks at the same object from different disciplinary perspectives with a low degree of integration. This is not the case here because multiple complementary concepts (e.g. scale, stakeholder) from different fields of science are used together in the proposed framework to build a single representation of a food chain. In this sense, interdisciplinarity can be distinguished from multidisciplinary by its capacity to blur disciplinary boundaries in order to provide new theoretical perspectives which enable a more coherent view of the object under study. For instance, the stakeholder group w name “Supply chain industrial network” was built using corporate management theory and provides the scope required to calculate employment using the input-output method. Like interdisciplinarity, transdisciplinarity connotes a research approach which crosses disciplinary boundaries in order to create a holistic approach, but transdisciplinarity goes further by emphasising the importance of the participation of non-scientists.

8.2. Integrated assessment

Second, according to (Pope *et al.*, 2004) *“ the term ‘integration’ implies that integrated assessment should be more than the sum of separate environmental, social and economic assessments.”* Thus to be fully integrated, the concept behind the definition of the basis of a given assessment method (scope, inventory) have to be investigated to be interrelated with new concepts. Dimensions of sustainable development have long been studied separately (Pope *et al.*, 2004). Here, we present an approach that is not only able to account for all three dimensions but also for the interrelations between these dimensions. Using this framework enables integrated assessment because it “*describes […]the relation between the human communities concerned, their economic organization and their resources base” and “[…] quantifies, and, as far as possible, values the effects of proposed and alternative interventions on the three (economic, social and natural) subsystems and their intersystem relations*” (Post *et al.*, 1998). For instance, the scale of the analysis is defined to capture elements of both the social and the ecological sub-systems: impacts on firms, on society and on nature. In the same way, stakeholder theory is applied to both social and the ecological subsystems. This means both social and environmental concerns can be considered as stakeholders (human and non-human stakeholders) and thus incorporates the two concerns as equal issues in management activities. Through this framework, the concept of cut-off criteria commonly used in environmental impact assessment is extended to socio-economic impact assessment. Salient human and non-human stakeholders linked with the supply chain are selected according to the appropriate cut-off criteria for each group of stakeholders but also, still based on the same criteria, the strength of the effect. For example, interaction of the supply chain with the stakeholder group “community” can be investigated from the point of view of its impact on health or from the point of view of its impact on employment, both using the same inventory dataset. However, the resulting system boundaries differ between evaluated dimensions and corresponding assessment methods. At first sight, this could be considered as a limit to the incorporation of methods but in reality boundaries are built on same principles (e.g. cut off criteria) and the social and the ecological subsystems are fundamentally different, justifying two different boundaries.

9. Conclusion

In this paper, we propose an integrated transdisciplinary conceptual framework to assess food chains' progress toward sustainability. First we highlight several weaknesses in the neoclassical economics and eco-efficiency approaches which fail to take important sustainable development principles into account. These principles can be better taken into account by combining approaches in a coupled system model. From a geographical point of view, the proposed framework makes it possible to define a spatial scale for the evaluation to check equity and efficacy, two basic principles of sustainable development. A clear delimitation of spatial scale facilitates the bottom-up emergence of the territory stakes, which helps identify those that are most relevant. The proposed framework refers to several theories of corporate organization (e.g. stakeholder theory, game theory) which can be combined to identify human, non-human, and social group stakeholders of the social ecological system. To make the framework operational, we recommend concentrating the analysis on the most relevant stakes and the most salient stakeholders. The salience of stakeholders is evaluated on the strength of their interactions with the food chain. Our framework underlines the need to consider the feedback loop as the loss of shared value for external stakeholders that indirectly affects the community; while this community often supports the activities of the food chain. If this feedback loop is perhaps not indispensable in industrial areas or business sectors, it could be very important in rural areas where the main activities of the food chain (i.e. farming activities) usually occur. The spatial differentiation of impacts calculated using different methods of assessment (e.g. environmental life cycle assessment or input-output analysis) and the downscaling of planetary boundaries to territories, and even to corporate scales, should - in the future - enable us to consider the environment as an essential variable in corporate management. Consequential analysis is highly recommended in preference to static evaluation for a fuller assessment of the positive or negative interactions between stakeholders and the supply chain concerned. A transdisciplinary approach is also highly recommended for optimal implementation of the proposed framework because both non-scientific and scientific stakeholders (including scientists from different fields) are needed to develop a holistic representation and analysis of the most probable dynamics of the food chain and of its impacts. The proposed framework was applied to a structured livestock supply chain in a very clearly delimited territory (see companion paper, Part 2) but further studies on different food chains in a broader context are needed to demonstrate the genericity of our framework.

Chapitre 1 – Chapitre 2

L'objectif du chapitre 1 était la construction d'un cadre conceptuel permettant de mettre en place une évaluation de la contribution d'une filière agricole au développement durable de son territoire. Ce cadre conceptuel repose sur différents apports théoriques aboutissant à l'élaboration d'indicateurs traduisant des enjeux territoriaux, en accord avec les aspects fondamentaux de la notion de développement durable. Le concept de système socio-écologique a été choisi comme schéma directeur pour évaluer le développement durable. Ce choix conduit à considérer l'objet d'étude, la filière avicole réunionnaise, comme faisant partie intégrante de deux sous-systèmes: le système social et le système écologique. Ce système a été placé dans un référentiel spatial et temporel dans lesquels évoluent différents types de parties prenantes. Les types de parties prenantes du système social sont identifiés à l'aide de concepts issus de théories du management stratégique. Les types de parties prenantes du système écologique sont identifiés à l'aide de méthodes de caractérisation d'impacts environnementaux. Enfin, le cadre conceptuel propose de se concentrer sur un groupe représentatif de parties prenantes non exhaustives. Ce groupe est identifié à l'aide de critères de coupure basés sur l'intensité de leurs relations avec la filière. Plusieurs méthodes ont été identifiées pour évaluer les effets de la filière sur ces parties prenantes.

Dans les chapitres 2 et 3, nous souhaitons appliquer séparément deux des méthodes d'évaluation à notre cas d'étude (cf. Chapitre 1§7) : l'analyse de cycle de vie environnementale et la méthode des effets. Le choix de ces méthodes est issu des conclusions d'une revue de la littérature présentée au congrès « *Life Cycle Management* » à Berlin en 2011 (cf. Appendice 4). Dans un premier temps, cette étape de notre démarche a pour objectif d'identifier les particularités méthodologiques liées à l'application de ces méthodes d'évaluation sur le cas d'étude, une filière de production animale. Les filières animales présentent en effet des caractéristiques particulières telles que des cycles de production longs, la multifonctionnalité des exploitations, les incertitudes liées aux pratiques des éleveurs, à leurs équipements, aux aléas climatiques, etc. qui conditionnent l'utilisation des méthodes à mettre en œuvre (p. ex. inventaire de cycle de vie, remontée de chaînes, etc.) dans chacune des deux méthodes d'évaluation. Ces particularités doivent être appréhendées dans un premier temps dans le cadre d'utilisation classique de ces méthodes afin de réaliser les adaptations nécessaires à l'application du cadre conceptuel par la suite. Dans un second temps, cette étape a pour but d'identifier la compatibilité de ces méthodes d'évaluation avec le cadre conceptuel et les adaptations à réaliser en vue d'une intégration conjointe. Trois critères conditionnant la compatibilité avec notre cadre conceptuel ont été retenus. La filière étant notre objet d'étude, le premier est la possibilité pour la méthode d'évaluation sélectionnée d'être utilisée pour évaluer un système de type *filière.* Le deuxième critère retenu est la possibilité de spatialiser les effets calculés afin de pouvoir développer un indicateur d'équité intra-générationnelle c.-à-d. d'équité interterritoriale. Enfin, nous souhaitons que les indicateurs des différentes méthodes d'évaluation soient liés à des paramètres d'inventaire commun. Le troisième critère est donc la possibilité de convertir les flux à la base du calcul en flux monétaire ou en flux matériel.

Dans le chapitre 2, la méthode d'analyse de cycle de vie environnementale (ACV; (Guinée *et al.*, 2002)) est appliquée sur le principal produit commercialisé par la filière volaille, le poulet blanc. L'ACV est reconnue comme la méthode d'évaluation environnementale de référence pour analyser les impacts environnementaux d'un produit ou d'un service (Guinee *et al.*, 2011). Ses applications classiques sont la comparaison de processus et l'affichage environnemental. Lors de travaux préliminaires sur l'efficience énergétique et les émissions de gaz à effets de serre des élevages à La Réunion (Thévenot *et al.*, 2010), nous avions rencontré une certaine incertitude sur les résultats des bilans énergétiques des exploitations (Vayssières *et al.*, 2011). Les exploitations d'élevage avaient été identifiées comme la source de cette incertitude. La finalité de l'outil développé pour la filière avicole est de pouvoir identifier des scénarios permettant la réduction de son impact environnemental, puis de pouvoir les hiérarchiser en vue de proposer des recommandations aux différents maillons de la chaîne de production. Cette incertitude devient donc problématique et doit être gérée.

Dans le chapitre 2, nous proposons de maitriser cette incertitude en couplant l'étape d'inventaire du cycle de vie à une analyse typologique basée sur des critères de niveaux d'équipement des bâtiments et de pratiques des éleveurs.

Chapitre 2

Accounting for farm diversity in Life Cycle Assessment studies – the case of poultry production in a tropical island

***Published** in Journal of Cleaner Production*

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Abstract

The farm is the most influential stage of agricultural production because farming practices affect both pre-farm and on-farm environmental impacts. Since farm diversity is not usually taken into consideration, it is legitimate to question the interest of including it in Life Cycle Assessment (LCA) studies. This work explores several approaches to modelling the farm stage when assessing the environmental impact of an agricultural supply chain in a context with variable farm performances. A LCA of a poultry supply chain was applied from cradle-to-slaughterhouse gate. The first approach is a classical one in which farm diversity is not taken into account and an average farm is constructed on the basis of weighted average farm characteristics. The second approach distinguishes four farm types identified by cluster analysis, and four LCA were performed according to these farm types. Farm types were distinguished based on their consumption of inputs and the type of ventilation of the farm buildings. Results indicate that the classical approach is sufficient to highlight problem hotspots and to identify promising mitigation measures. Reducing the transport distance of imported maize, improving feed conversion efficiency and anaerobic digestion of slaughterhouse animal wastes were identified as appropriate mitigation measures. As feed production and poultry rearing are the stages with the most impact, distinguishing farm types provides i) insight into farm functioning to better explain the variability of environmental impacts and understand how to reduce them, ii) reduce the uncertainty of results, and iii) provide appropriate recommendations for mitigation measures. Coupling a farm typology with the LCA is particularly useful when farming systems are very diverse like in Reunion Island where the climate varies considerably across the island.

Keywords: Life Cycle Assessment; Cluster analysis; Mitigation scenarios; Uncertainty; Broiler Supply chain; Reunion Island

1. Introduction

It was demonstrated many years ago that livestock industries have a major impact on the environment from local to global scale (FAO, 2010). Life Cycle Assessment (LCA) is a useful tool to assess impacts at different scales and to highlight problem hotspots throughout the life cycle of a product (Haas *et al.*, 2000). In agricultural systems, most resources are consumed and most emissions into the environment occur during the on-farm stage (Ellingsen and Aanondsen, 2006; Eriksson *et al.*, 2005). For industrial monogastric livestock system, poultry for instance, the pre-farm stage is also important because the feed is usually produced off-farm (De Haan *et al.*, 1997). In both cases, the farm is the most influential stage because it affects both pre-farm and on-farm environmental impacts. Unlike other industries, agricultural systems are subject to variability which is inherent to both the system and its environment. Due to the resulting uncertainty, the answers provided by LCA may be incomplete or erroneous (Huijbregts *et al.*, 2001). Even if industrial monogastric livestock systems are generally standardized (De Haan *et al.*, 1997), all agricultural systems have to deal with biotic and abiotic stresses which affect their production, resource consumption, and emissions from a flock, or from one harvest to the next (Basset-Mens *et al.*, 2006). The rearing method (e.g. conventional versus organic farming) also has major consequences for the final results (Boggia *et al.*, 2010). Variability increases even more when considering systems functioning under difficult climate conditions (e.g. tropical arid) or contrasted relief (e.g. high altitude, narrow territory) or when the level of technology varies considerably between the different types of farms (e.g. between smallholder low-input crop-livestock integrated systems and intensive production systems) (Al-Aqil *et al.*, 2009; Herrero *et al.*, 2010). Like other methods of assessment, LCA requires the widest possible data inventory to obtain the most realistic results possible. For the assessment of agricultural products, data is usually collected through farm surveys, which are expensive and time consuming. Assessing an agricultural product could mean basing the assessment on only a small sample of highly variable farms, hence the risk of incorrect results.

In the literature, one farm is usually modelled to represent the production step. Several ways of modelling this step can be found: random or oriented selection of an actual farm (Cederberg and Mattsson, 2000; Knudsen *et al.*, 2010), construction of a theoretical farm using a range of data sources (Beauchemin *et al.*, 2010; Castanheira *et al.*, 2010; Halberg *et al.*, 2010; Ogino *et al.*, 2007; Pelletier, 2008), or construction of an average farm based on observed data collected from a sample of farms (Basset-Mens *et al.*, 2009; Haas *et al.*, 2001;

Pelletier *et al.*, 2010). The first option, i.e., random selection is generally not recommended because of the high risk of obtaining a non-representative sample. In the case of oriented selection, the main criticism is subjectivity. The second option, i.e. the construction of a theoretical farm, is widely used for assessment at regional or national scale. In the third option, i.e. the construction of an average farm, the quality of the average farm is strongly influenced by the size of the sample. In all three cases, the studies generally fail to take farm diversity and variability into account. Another option is to distinguish farm types using cluster analysis, and then to define an average farm for each type. This method has been used for several other purposes including farm simulations (Kobrich *et al.*, 2003; Righi *et al.*, 2011) but only rarely in LCA (Dalgaard *et al.*, 2006).

The present study examines the chicken industry in Reunion Island (a French tropical island in the Indian Ocean, 700 km east of Madagascar). In Reunion, eating chicken meat has no religious or cultural connotations, and is the most widely consumed meat (AGRESTE, 2008). One cooperative and two industrial firms comprise main poultry supply chain, which supplies about 27% of the local demand for chicken meat for a population of around 850,000 (IEDOM, 2008). Future population growth will require these firms to double their production over the next ten years while facing several constraints. First, supply chain decision-makers have to deal with the narrowness of the territory and the risk of extreme climatic events (hurricanes) which limit cereal production. Geographic isolation also complicates access to inputs (e.g. spare parts for machinery, ingredients, choice of packaging) and waste treatment (Christofakis *et al.*, 2009). Consequently, most raw materials and equipment used in the supply chain are imported over long distances hence increasing both operating costs and environmental impacts.

Secondly, the poultry farms are located in contrasted relief (elevation ranges from 0 m to 2540 m on an island that covers only 2,512 km²) which complicates logistics and is a major obstacle to the creation of large farms, making economies of scale difficult to achieve. Moreover, temperature and humidity varies a great deal depending on the time of day, the season, the altitude and the location of the farm, which increases the difficulty of maintaining optimum conditions for poultry. In addition, not all farmers can afford the additional costs of equipment (e.g. dynamic ventilation systems). These constraints incur unequally to farmers and consequently result in variability in performance. At the end of the chain, the consumer obtains a local product on the same market but with variable economic and environmental performances depending on the location of the farm.

The objective of this study was to examine the interest of including a farm typology in the LCA to improve the reliability of results of LCA studies. We chose to use the poultry supply chain in Reunion Island as a source of data. First, we applied LCA using a standard farm modelling method to identify a first set of promising mitigation measures. Second we tested the use of representative farm types for environmental diagnosis and to evaluate the relevance of the previously identified mitigation measures, this time taking farm diversity into account. In the final section of the paper, we discuss several methodological issues we encountered.

2. Material and methods

2.1. Farm typology and modelling methods

Two methods for farm modelling are described in this paper. The first is a standard method based on a single farm using average data from the whole sample which is assumed to be representative of the actual farm population. The second method distinguishes different farm types and is based on many average farms that are representative of each farm type, i.e. one farm is modelled per farm type. Farm models and LCA results (obtained using the two farm modelling methods) are based on the same inventory dataset taken from a single questionnaire used to survey 42 farms. The 42 farms represented 55.3% of the farms that belong to the poultry supply chain and supply 56.3% of the total weight of poultry slaughtered each year. The 42-farms sample was based on criteria chosen in collaboration with experts, with the objective of covering the geographical and technical diversity. The criteria for sampling were the altitude of the farm (low, medium, high), its location (north, south, west, east), and its level of mechanization (natural or dynamic ventilation of the building in which the poultry are raised).

During the farm survey, a set of 25 parameters was collected to build the typology and the farm models, and to feed the LCA inventory. These parameters were grouped in three categories: parameters that affect the atmosphere in the poultry buildings (e.g. quality of the building, natural or dynamic ventilation, density of birds), technical performance parameters including farm production (e.g. average daily weight gain, average live weight on arrival at the slaughterhouse, average age on arrival at the slaughterhouse, mortality rate) and data on the consumption of inputs on the farm (e.g. chicken feed, electricity, gas). The complete data set is described in Table 4. The 25 parameters were extracted from farm revenue and expenditure accounts and cooperative databases, and validated with the farmers concerned during the farm survey.

In a first modelling approach, the input and output parameters of the farm model were calculated as the mean of the characteristics of the 42 farms (including consumption of inputs and production of outputs) weighted by their relative contribution to total chicken production in tonnes. The second farm modelling method distinguished a specific farm model for each farm type determined by cluster analysis. To determine the types, the analysis included the following steps: i) a principal component analysis was performed on the standardized set of variables, ii) a hierarchical cluster analysis of the scores of the first principal component was conducted using Ward's method (Saporta, 1978). To select the appropriate number of clusters, we used the Silhouette clustering quality index described by Rousseeuw (1987). The principal component analysis procedure (step i) sought uncorrelated linear combinations (components) of the original variables such that the maximum variance was extracted from the variables (Sabatier *et al.*, 1989). Then, meaningful variables were identified from the loadings which measured the contribution of each original variable in the variance of the principal component. Variables with a loading (for a given component) that fell outside the 95% confidence interval of all the component loadings were considered to significantly contribute to the component. The hierarchical partitioning (step ii) seeks to build clusters using Ward's minimum variance criterion which minimizes total within-cluster variance. For each partition, the Silhouette index (step iii) measures how tightly all the data are grouped in each cluster. If there are too many or too few clusters, some of the clusters will display much narrower silhouettes than the rest. The highest mean of silhouette widths indicates the appropriate partition (Rousseeuw, 1987).

The cluster analysis and validation was processed with open-source R software (R Development Core Team, 2005) using the *ade4* package (Thioulouse *et al.*, 1997) for principal component analysis, the *Stats* package for hierarchical cluster analysis, and the *cluster* package to compute the silhouette information from the clustering. For each farm type, an average representative farm was built from the mean of inputs and emissions for all the farms belonging to the type, weighted by their relative contribution to total chicken production of the farm type in tonnes.

2.2. Life cycle assessment

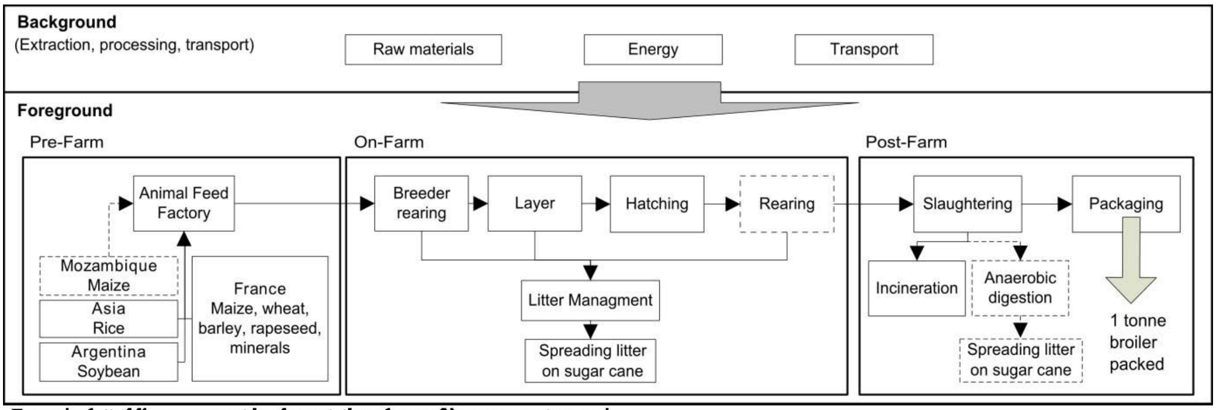
LCA allows the environmental impacts of a product or service to be calculated throughout its life cycle. ISO 14040 and ISO 14044 define four distinct stages for life cycle assessment: definition of goals and scope, inventory analysis, impact assessment, and interpretation of results (ISO, 2006). All impacts were calculated using Simapro v 7.3 software (PRé Consultants, 2008).

2.2.1. Goals and scope

Defining the goals and scope is a critical phase when the first important choices are made, including the functional unit, the system perimeter, and the scenarios to be compared (Guinée *et al.*, 2002). The objective of the LCA presented in this paper was to evaluate the use of resources and the environmental impacts of the poultry supply chain from cradle-to-slaughterhouse expedition gate in Reunion Island under different scenarios designed in collaboration with local stakeholders. The results were destined for local industry and policy makers. The main poultry supply chain in Reunion Island is well organized thanks to a clear division of tasks and to the support of an inter-professional association, which ensures strong cohesion between firms (Lucie Ploquin, 2011). The study was carried out in close co-operation with local stakeholders thus giving us easy access to site specific data. This study provides robust data concerning the post-farm stage, which is often lacking in LCA studies (Davis and Sonesson, 2008).

The functional unit used was a reference unit to allow us to express all inventory flows in the same unit. As the primary function of the system is to provide fresh poultry meat to consumers, the functional unit chosen was one tonne of whole chickens packed and ready for transport to supermarkets (bones were included but feathers, head, blood, intestines, liver and heart were excluded).

The system under study covers the whole life cycle of broilers including the production of resources and waste treatment with associated emissions (see Figure 5). To facilitate the analysis, the central production processes were grouped in three main stages: i) the pre-farm stage including crop production and processing of poultry feed, ii) the on-farm stage including producing one day old chicks (breeding, laying and hatching) and rearing broilers (feeding and manure management), and iii) the post-farm stage corresponding to the slaughterhouse (slaughtering, packaging, and waste treatment). The background processes of the system correspond to the production of energy and raw materials (other than crop products) and transport.



Boxes in dotted lines represent implementation places of improvement scenarios.
Scenario MOZ is located in Mozambique, scenario FE is implemented on the rearing farm and scenario AD is implemented next to the slaughterhouse plant both located in Reunion Island.

Figure 5: System boundaries for to the cradle-to-slaughterhouse production of one tonne of broiler chicken packed and ready for dispatch.

The baseline scenario (TEM) was the supply chain in the period 2007-2009. Four mitigation scenarios corresponding to proposed measures to improve the pre-farm, on-farm and post-farm stages were analysed in comparison with the baseline scenario. In the first scenario (MOZ), maize is imported from Mozambique instead of from Europe. Maize represents more than 50% of broiler feed and is currently imported from Europe, i.e. over a distance of 10,000 km whereas closer countries located in the Indian Ocean could supply Reunion Island (assuming that economic and political barriers are overcome). The second scenario (FE) is based on the hypothesis that all the farms have the necessary technical facilities and equipment to achieve optimal feed efficiency of 2 kg of feed consumed per kg of broiler produced possible with the genetic origin of this broiler, i.e. in 47 rearing days. In the year 2007, only around one quarter of the farms in the sample reached this goal. For the others, feed consumption was reduced to 2 kg per kg of live weight broiler produced and the electricity consumption was increased according to the technical and management changes that were needed (e.g. additional energy use for a dynamic ventilation system). In the third scenario (AD), slaughterhouse wastes are treated by anaerobic digestion instead of incineration. Viscera, sludge, blood, and droppings are normally burned in an incineration plant implying high energy consumption and resulting in high emissions into the atmosphere, and requiring the treatment of hazardous wastes. In the AD scenario, chicken wastes are processed in a biogas digester with added pig slurry. The fourth scenario (COM) combines the three mitigation measures; i.e. the simultaneous implementation of all the three mitigation scenarios (MOZ, FE and AD). It should be noted that the resulting environmental impact reductions are not the simple sum of the reductions of the three others. Technical interactions exist between MOZ and FE scenarios.

2.2.2. Supply chain functioning and inventory analysis

Inventory analysis consists in quantifying all extractions and emissions (elementary flows) that cross the limits of the system (Guinée *et al.*, 2002). Each process was analysed for resources use, emissions into the environment, and products entering and exiting the system. Data were mainly collected from local firms and when necessary (rarely) completed with data from the literature and regional statistics.

Pre-farm stage

One of two existing animal feed suppliers was surveyed (the two firms are very similar). Data were collected concerning the origin of the raw materials. All the raw materials required for the poultry feed concentrate were imported, mostly cereals and premix from Europe, and soybean meal from Argentina. Inventory data for raw materials and crop production were taken from the study of Boissy *et al.* (2011). Data on the processing of raw materials into feed concentrate and delivery to farms were provided by one of the two animal feed suppliers on Reunion Island who supply feed to 80% of poultry farms (the two feed suppliers are very similar in terms of size and equipment). Feed concentrates differ in composition and consequently in nutrient value depending on the stage of development of the broilers. Four feed concentrates are used by broiler farmers. The composition of each feed concentrate was calculated based on the annual average composition for 2007. Average feed formulae and the origin of the raw materials are listed in Table 2.

Table 2: Mean ingredients (% of diets) of four feed concentrates used locally: pre-starter, starter, grower and finisher

	Pre-Starter (%)	Starter (%)	Grower (%)	Finisher (%)	Country of origin
Maize	47.4	51.8	51.7	54.9	France
Soybean meal	34.8	29.8	27.7	26.6	Argentina
Wheat	9.7	9.2	8.3	7.9	France, Mauritius
Different types of straw	1.8	1.2	3.3	4	France
Calcium carbonate	2	1.8	2.2	2	South Africa
Vitamin mineral premix	1.3	1.3	1.3	1.3	France, Brazil, China
Calcium phosphate	1.5	1.1	1.1	1.1	Tunisia
Soybean oil	0.8	0.7	0.4	0.2	Argentina

Other	0.7	3	3.9	1.8	-
Salt	0.1	0.1	0.1	0.1	Namibia, India
Crude protein	20.8	19.3	19	18.2	

<u>On-farm stage</u>

Production data and inventory for broiler farms were summarised in farm models: i.e., a single farm or farms representative of the types (see section 2.1). The majority of on-farm gaseous emissions occur during rearing and manure management. According to a study on poultry farming by Guiziou and Beline (2005), CH_4 and N_2O emissions are negligible and nitrogen (N) gaseous emissions are mainly in the form of NH_3. It was not possible to measure NH_3 emissions on each of the 42 farms. But to account for farm diversity, ammonia emissions were calculated for each farm based on the difference between farm N outputs and inputs (Bassanino *et al.*, 2007; Gustafson *et al.*, 2003; Hedlund *et al.*, 2003). Nitrogen inputs came from feed concentrate and fresh litter and their N contents were obtained from the feed and litter suppliers respectively. Nitrogen outputs are broiler carcasses, culled animals, and manure. Nitrogen content of carcasses, both sold and culled, was estimated based on standards reported in the literature (Rouffineau, 1997). Mortality rates and weights of dead animals came from a technical survey of each farm conducted by the cooperative. Manure N content was estimated from local references (Chabalier, 2006).

The on-farm inventory concerned two rearing units, three hatch egg producers and two hatcheries, all located at a distance of 20 to 80 km between each unit and between hatcheries and rearing farms. These farms supply all the broiler farms in Reunion Island with chicks. Breeders are imported from mainland France at one day old and are reared to supply the broilers farms with one day old chicks. The same nitrogen balance method used for broiler farmers was used to estimate ammonia volatilisation for the producers of eggs and chicks.

<u>Post-farm stage</u>

The only slaughterhouse in the main broiler supply chain, sized to slaughter 23 000 broilers per day, provided us with data for the broiler slaughtering processes. Data was collected for the period 2007-2009 (Lucie Ploquin, 2011). For slaughterhouse operations, all inputs (e.g. electricity, packaging, water) for each process from arrival to dispatch were monitored. Based on observed purchases, the yearly loss rate of refrigeration gases over time was estimated at 13% of the total stock of machines. Slaughterhouse animal wastes are transported a distance of 600 metres by truck to an incineration plant. The incineration plant, which deals with both culled farm animals and slaughterhouse wastes, was also surveyed. All emissions and inputs were accounted for based on annual emissions from the building and revenue and expenditure accounts.

Background

The local electricity mix was rebuilt based on the EcoInvent process structure using local specific data on the energy mix and the origins of the fuel (OER, 2008). Data for transport, water, and waste treatment were derived from EcoInvent Database 2.0 (Doka, 2009; Dones *et al.*, 2004; Spielmann *et al.*, 2007).

Scenarios

Data in the improvement scenarios were based on on-going projects together with forecast reports from consultancy agencies. For the first scenario (MOZ), the transport distance from Beira port (Mozambique) to the port in Reunion Island was evaluated and maize technical operations in Mozambique were assessed using local average data for a large maize production area with high expansion potential (IIAM, 2011). Direct emissions from maize fields were estimated according to (Nemecek and Kägi, 2007). For the second scenario (FE), we reduced the dietary burdens to that score and used the corresponding ammonia gaseous emissions. In the third scenario (AD), biogas and heat generated are destined to be used as a substitute for fuel in the currently oil-fired boiler system for the slaughterhouse and were consequently converted into fuel equivalent according to their respective lower heating value. The solid output of the digester is assumed to be used as fertilizer for sugar cane production. The liquid part is treated in the communal waste water treatment plant.

2.2.3. Allocation rules

Reports in the literature emphasize that many agricultural processes are multifunctional. According to ISO14041, when allocation could not be avoided, emissions and consumption of raw materials were allocated to reflect the physical relationship between products (ISO, 1998). In our case study, the economic allocation method was applied to the whole supply chain except for manure and waste management for which system expansion was used.

Pre-farm

The two animal feed firms also supply feed for several animal species (cattle, pigs, rabbits, etc.). The allocation of consumption and emissions between animals was based on the economic value of the feed produced for each species.

On-farm

For hatch eggs producers, the burdens were allocated between hatching eggs, culled animals and unfertilised eggs according to their economic value. For manure use there is currently no consensus on the method of allocation. Avoiding manure allocation by system expansion is the currently best compromise solution (Nemecek and Kägi, 2007). For system expansion, the system that produces the coproduct is extended to an alternative one which generates an equivalent product. In Reunion Island, the manure is removed from broiler farms after each round of poultry reared and is mainly used as fertilizer on sugar cane fields, so we expanded the poultry system to mineral fertiliser production and supply for sugarcane production. Manure was assimilated as an equivalent of avoided mineral fertilisers calculated on the basis of the N, P, K content of manure and the mineral fertiliser most commonly used for sugar cane (Dalgaard *et al.*, 2006). It was assumed that manure efficiently replaces mineral fertiliser on sugar cane fields. Impacts during manure collection, storage and land application were allocated to poultry production. And all impacts due to avoided production, transport and application of mineral fertiliser were credited back to poultry meat production. Used litter is removed from the building with an average of 22.5 g N content per kg of fresh product (Chabalier *et al.*, 2007). We considered 15% of NH_3 losses by volatilization during the 7-month litter storage period, 10% of NH_3 losses for application of litter (Rodhe and Karlsson, 2002) and 15% of NH_3 losses for application of mineral fertiliser. No significant losses due to leaching were observed during the application of organic and mineral fertiliser on sugar cane due to the quantity of mulch used (Oliveira *et al.*, 2002).

<u>Post-farm</u>

Broilers represent 90% of total production (in tonnes, all poultry species taken together) on arrival at the slaughterhouse. Economic allocation was also applied to allocate consumption of raw materials between the different species (turkey is the second most important species). Like manure, after processing, some of the slaughterhouse wastes (blood and feathers) are used as fertilizer on sugar cane fields. The N supply to sugar cane was estimated on the basis of the N content of the treated wastes. Like for manure, avoided production and transport of mineral fertilizer was credited back to waste treatment as the system was expanded.

2.2.4. Life cycle impact assessment

The impact categories considered in this study were chosen according to the review of de Vries and de Boer (2010) in order to be comparable with the majority of studies on animal products: acidification potential (SO_2 equiv.), eutrophication potential (PO_4 equiv.), global warming potential (CO_2 equiv.), and energy use (MJ). Acidification and eutrophication potentials were quantified according to the CML 2 Baseline 2000 method (CML, 2001). Global warming potential (GWP 100 years) in kg CO_2eq using the Intergovernmental Panel on Climate Change estimate (IPCC, 2001). Energy use was quantified in MJ following the cumulative energy demand method v1.08 (VDI, 1997). Life cycle impact assessment was performed using these methods because of their problem oriented mid-point approach which allows the potential environmental impact rather than damage levels to be taken into account.

2.3. Uncertainty analysis

ISO standard 14043 recommends taking into account the uncertainty in the presentation of the LCA results (ISO, 2000). Two major sources of uncertainty were taken into account, one focusing on emission factors and the other based on farm modelling methods, as this was the main focus of the present study.

Ammonia emissions from buildings during rearing and from manure during storage and after application have significant impacts on potential acidification and eutrophication (Krupa, 2003). However, wide ranges of emission factors for ammonia volatilisation are reported in the literature (Meda *et al.*, 2011). Consequently, an uncertainty analysis in N losses to the environment was performed to compare our results with those of other works. Estimates of uncertainty in NH_3 volatilisation rates were calculated using the method proposed by Payraudeau *et al.* (2007). Monte Carlo analysis (10,000 simulations) was performed using R software (R Development Core Team, 2005).

Despite the fact that industrialised poultry production systems are generally standardised (De Haan *et al.*, 1997), the survey revealed significant variations in structure, practices and technical performance between farms. For that reason, a second Monte Carlo analysis (1,000 simulations) was performed using Simapro v7.3 software to analyse the uncertainty of the impact categories mentioned above. Standard deviations of all inputs and emissions were used to generate the 1,000 simulations for both the single average farm and the representative farm types.

3. Results

3.1. Results of the LCA based on a single average farm model

Table 3 lists the environmental impacts in the categories acidification potential, eutrophication potential, global warming potential and energy use for one tonne of whole chickens' packaged ready for dispatch from the slaughterhouse based on the single average farm. Results are organised so as to distinguish between the three main stages of the supply chain: poultry feed production (i.e. the pre-farm stage), poultry rearing (i.e. the on-farm stage), and slaughterhouse processing (i.e. the post-farm stage). Production of poultry feed was responsible for the majority of environmental impacts considered except for acidification potential. At the slaughterhouse gate, animal feed accounted for 75% of global warming potential, 68% of energy use, and 50% of eutrophication potential. The major contributor to acidification potential and second contributor to energy use is the poultry rearing stage, mainly due to direct ammonia emissions. Slaughterhouse processing contributed significantly to both energy use and global warming potential impact categories.

Table 3: Values and contributions (in brackets) of the three main stages to total environmental impacts (in bold), and relative contributions of the unit processes to environmental impacts of each main stage (in italics).

	AP kg SO_2 eq	EP kg PO_4--- eq	GWP kg CO_2 eq	EU MJ
Production of poultry feed = Pre-farm stage	**15.6 (21%)**	**14.1 (50%)**	**1878.1 (75%)**	**23875 (68%)**
- Main crops	*51%*	*87%*	*66%*	*52%*
- Other crops	*6%*	*7%*	*10%*	*17%*
- Maritime transport	*35%*	*4%*	*12%*	*15%*
- Road transport	*3%*	*1%*	*7%*	*10%*
- Processing	*4%*	*1%*	*5%*	*6%*
Poultry rearing = On-farm stage	**57.7 (77%)**	**13.5 (48%)**	**353 (14%)**	**6 635 (19%)**
- Hatching chicks	*13%*	*18%*	*57%*	*41%*
- Transport (chicks, feed, other)	*1%*	*1%*	*23%*	*20%*
- On-farm emissions	*75%*	*70%*	*0%*	*0%*
- Electricity	*2%*	*3%*	*55%*	*40%*
- Other non-renewable energy	*0%*	*0%*	*6%*	*27%*
- Other (wood pellets, water, rendering)	*0%*	*0%*	*2%*	*15%*
- Manure (system expansion)	*9%*	*8%*	*-42%*	*-43%*
Slaughterhouse processing = Post-farm stage	**1.7 (2%)**	**0.5. (2%)**	**257 (10%)**	**4 475 (13%)**
- Energy	*30%*	*29%*	*28%*	*30%*
- Cold production	*10%*	*9%*	*14%*	*7%*
- Packaging	*11%*	*6%*	*16%*	*25%*
- Animal waste	*28%*	*28%*	*13%*	*11%*
- Other wastes	*4%*	*15%*	*4%*	*3%*
- Transport	*17%*	*12%*	*25%*	*24%*
Total	**75**	**28**	**2489**	**34985**

Impact categories are acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), and energy use (EU)
The environmental impacts are expressed for one tonne of whole chickens packed ready for dispatch from the slaughterhouse gate.
Table 3 also details the relative contribution to environmental impacts of the unit processes in the three main stages.

3.1.1. Poultry feed production

The three main crops produced (maize, soybean and wheat) are the major contributors to the environmental impacts of poultry feed production i.e. 51% of the total impact of acidification potential and energy use, 87% of eutrophication potential and 66% of global warming potential. Maritime transport of raw materials contributed to 35% of acidification potential and 12% and 15% of global warming potential and energy use because all raw materials are imported from the European Union and from Argentina, over a distance of more than ten thousand kilometres. Closer countries could supply the Reunion Island demand for cereal, Mozambique for instance. A transport improvement measure was then explored (Scenario MOZ, see section 2.2.1).

3.1.2. Broiler rearing

On-farm emissions contributed most to acidification potential and eutrophication potential impact categories. Ammonia volatilisation depends on manure characteristics (pH, temperature, N content and moisture) and decreases inside the buildings with a decrease in temperature. Under tropical climate conditions, higher ventilation rates are required to ensure acceptable indoor temperatures for broilers. In Reunion Island, about half the farms use natural ventilation which does not enable optimal temperature control. Poor control of temperature inside the buildings results in low feed conversion efficiency and an increase in ammonia emissions (Al-Aqil *et al.*, 2009). The indoor atmosphere directly affects feed conversion efficiency and ammonia emission per kg of animal product, which was why an improvement measure was explored at this step (Scenario FE, see section 2.2.1). System expansion for manure management using avoided burden of fertiliser production offset 42% and 43% of global warming potential and energy use impacts in the rearing stage.

3.1.3. Slaughterhouse processing

The contribution of the slaughterhouse to energy use and global warming potential is mainly the result of electricity consumption for slaughtering operations (hot water, steam generation and operating the machines) and for the incineration of animal wastes. Incineration requires a lot of energy and smoke purification residues are exported to Europe for treatment and then used as landfill. Consequently waste treatment by incineration also contributes significantly to global warming potential and energy use. For that reason, an improvement measure was explored at this step (scenario AD, see section 2.2.1).

3.1.4. Uncertainty analysis

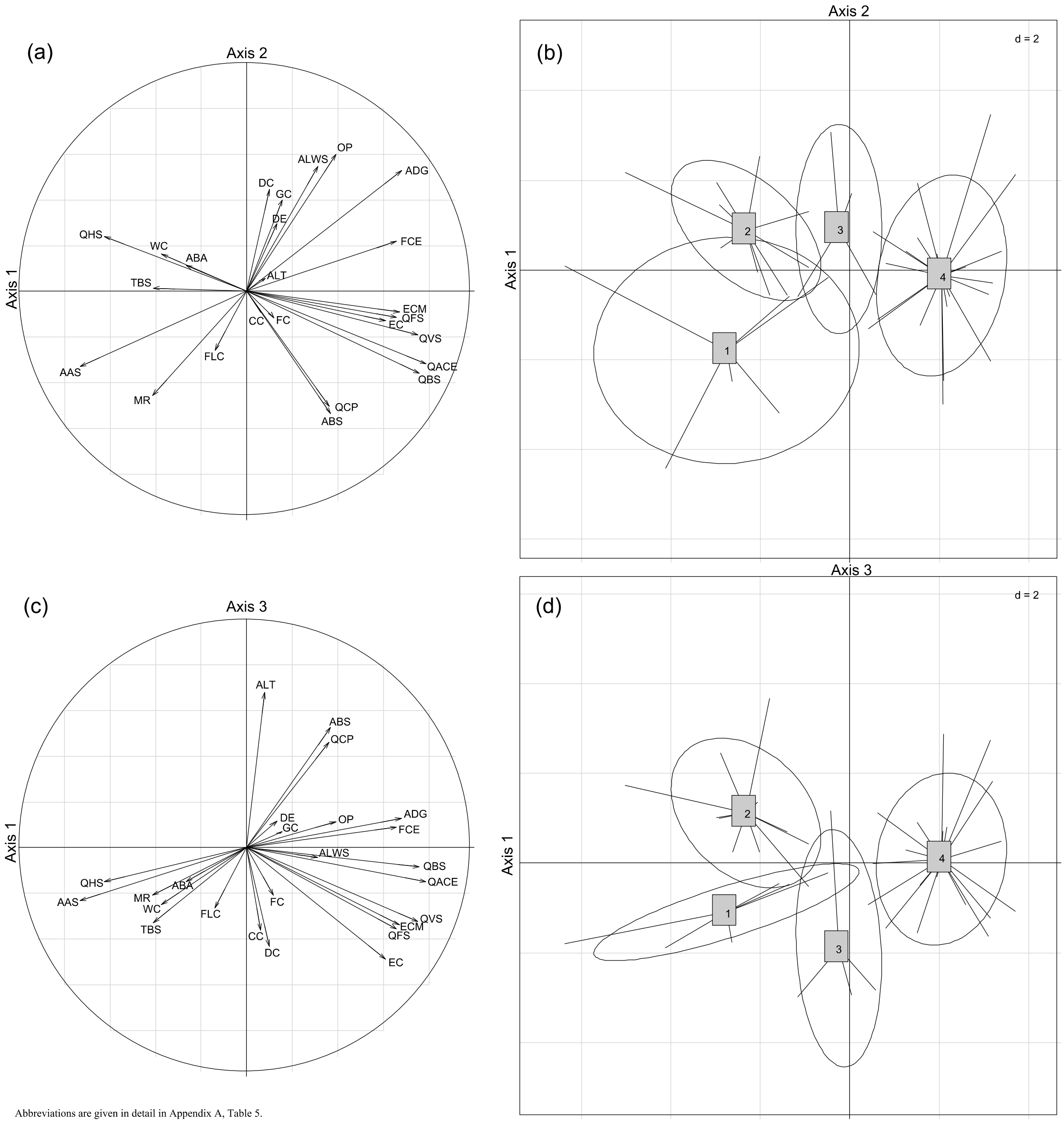
Section 2.3 underlined the need to analyse the uncertainty of the farm N balance input parameters which affect the calculation of ammonia emission. Monte Carlo analysis showed an average of 0.72 g NH_3 bird^{-1} day^{-1} which is higher than the 0.16 g NH_3 bird^{-1} day^{-1} reported in France by (Guiziou and Beline, 2005) but in the upper range reported in other European studies (Meda *et al.*, 2011). The coefficient of variation of the NH_3 volatilisation rate was about 10% of the mean for the 42 farms, leading to coefficients of variation of 6.0% and 2.8% of the mean for the acidification potential, eutrophication potential impact categories, respectively. Global warming potential and energy use were not directly influenced by NH_3 volatilisation, so the resulting coefficients of variation were very low.

Concerning the impact of farm diversity on results, the Monte Carlo analysis based on the characteristics of the 42 farms surveyed indicated coefficients of variation of 9.9%, 6.6%, 6.7% and 7.1% of the mean for respectively acidification potential, eutrophication potential, global warming potential, and energy use impact categories.

3.2. Results of the LCA based on farm models representative of farm types

3.2.1. Farm typology

Eigen values suggest selecting four principal components which represent 53.8% of the total variance of the data (not shown). The loadings for the four first principal components are presented in Appendice 2, Table 17. Fifteen variables were selected for discussion according to their significant contribution (variables in bold in Table 4) in the variance of the principal component. On the first principal component, average daily gain, building, ventilation and equipment quality score are inversely correlated with age at slaughter. On principal component 2, average daily gain, average live weight at slaughter and the overall productivity are inversely correlated with the quantity of chicken produced and the average building size. On principal component 3, altitude, quantity of chicken produced and average building size were inversely correlated with the electricity consumption. The graphic representation of the silhouette index shows that a four cluster partition is associated with the largest silhouette score (see Appendice 2, Figure 21). The contribution of the 25 original variables to principal components 1-2 and 1-3 is represented graphically in Figure 6a and Figure 6c, respectively. Figure 6b and Figure 6d represent the projection of farms aggregated by types on the same factorial plans, respectively.



Abbreviations are given in detail in Appendix A, Table 5.

Figure 6: Graphic representation of the projection of the 25 original variables on factorial plan 1-2 (a) and 1-3 (c) and graphic representation of the projection of the 4 types and corresponding farms on factorial plans 1-2 (b) and 1-3 (d).

Table 4 shows the average value for the farm characteristics variables per farm type. Maximum and minimum values are in **bold**. Type 1 (n=6) is characterised by farms with the lowest technical performance: low average daily gain, average live weight at slaughter, and high age at slaughter, resulting in the lowest overall productivity among all types. These farms are also characterized by large farms located at low altitude. Types 2 to 4 are distributed over a gradient on the principal component 1 in the factorial plan 1-2 (see Figure 6b). Following this gradient, the quality of building, ventilation system, and atmosphere control equipment increases. Based on this observation, type 2 farms (n=11) show less energy consumption (Electricity consumption, fuel oil consumption) than other types of farms. Type

3 farms (n=4) have the highest overall productivity but differ from type 2 and 4 farms by their high consumption of inputs per kg of chicken produced (Electricity consumption, feed conversion efficiency). Type 4 farms (n=21) represent half of the sample and have the best technical performances.

Table 4: Average values for variables per farm type. Representative variables are in bold. Maximum and minimum values are in bold.

Representative farm type		1 (n=6)	2 (n=11)	3 (n=4)	4 (n=21)
Consumption of inputs					
Diesel consumption	Litre per kg LWC*	0.32	**0.30**	**1.59**	0.55
Fuel oil consumption	Litre per kg LWC*	**0.0**	0.3	0.1	**1.6**
Water consumption	m^3 per kg LWC*	**1.7**	**1.0**	1.1	1.2
Chicks consumption	kg per kg LWC*	2.3	2.3	**2.2**	**2.5**
Fresh litter consumption	kg per kg LWC*	**17.1**	7.7	8.0	**5.7**
Gas consumption	kg per kg LWC*	**1.2**	1.7	1.3	**2.2**
Electricity consumption	kWh per kg LWC*	15.9	**9.1**	**30.5**	22.7
Technical performance parameters					
Density	kg per m²	**17.6**	18.5	**19.4**	18.4
Feed conversion efficiency	kg LWC* per kg feed	0.457	0.453	**0.439**	**0.490**
Mortality rate	%	**5.1**	**1.9**	2.6	2.7
Average age at slaughter	day	**49.1**	48.0	48.2	**46.7**
Average daily gain	g per day	**35.8**	37.2	36.7	**38.4**
Average live weight at slaughter	kg	**1.75**	1.78	1.76	**1.79**
Overall productivity	kg LWC*/m²/year	**155**	175	**181**	174
Electricity consumption / m²	kWh per m²	23	**15**	**48**	38
Quality of buildings and equipment					
Average age of buildings on the farm	years	13.9	**11.6**	14.2	**16.0**
Quality score of building	1 - 9	2.6	**2.2**	2.6	**3.7**
Quality score of heating system	1 - 3 (a)	2.0	**1.1**	2.2	**2.3**
Quality score of feeding system	1 - 3 (b)	2.3	**3.0**	**2.1**	**3.0**
Quality score of ventilation system	1 - 3 (c)	2.0	**1.5**	2.5	**2.9**
Quality score of atmosphere control equipment	1 - 4 (d)	2.5	**1.5**	2.0	**3.7**
Farm characteristics					
Total building surface	m² per kg LWC*	**0.76**	0.63	0.64	**0.61**
Average building surface	m²	428	420	**339**	**615**
Altitude	m	**275**	**573**	413	461
Quantity of live weight chickens produce	kg LWC*	124966	110936	**104824**	**155308**
Contribution to total production					
	%	13%	22%	**7%**	**58%**

*LWC: live weight chickens
(a) 1: Located, 2: Mixed, 3: All buildings
(b) 1: Manual, 2: Mixed, 3: Automatic
(c) 1:Natural, 2: Mixed, 3: Dynamic
(b) 0: No appliance, 1: 1 appliance. (electronic temperature control or thermometer or hygrometer or barometer), 2: 2 appliances, 3: appliances., 4: 4 appliances.)

3.2.2. Impact assessment per representative farm type

Figure 7 shows the results of life cycle impact assessment per type of farm with the relative contribution of each process. The LCA results of each farm were aggregated according to their type and weighted by the relative contribution to chicken production of their type. Type 3 has the most impact in all impact categories due to the fact their input use efficiency is the lowest. Low feed conversion efficiency applies in particular for acidification potential and eutrophication potential, and high electricity consumption for global warming potential and energy use. Type 4, despite higher feed conversion efficiency than Type 2, has nearly the same score for acidification potential, global warming potential and energy use because of high energy consumption. Type 4 has the lowest score for acidification potential and eutrophication potential because of limited on-farm NH_3 emissions. Type 1 has intermediate results in all impact categories.

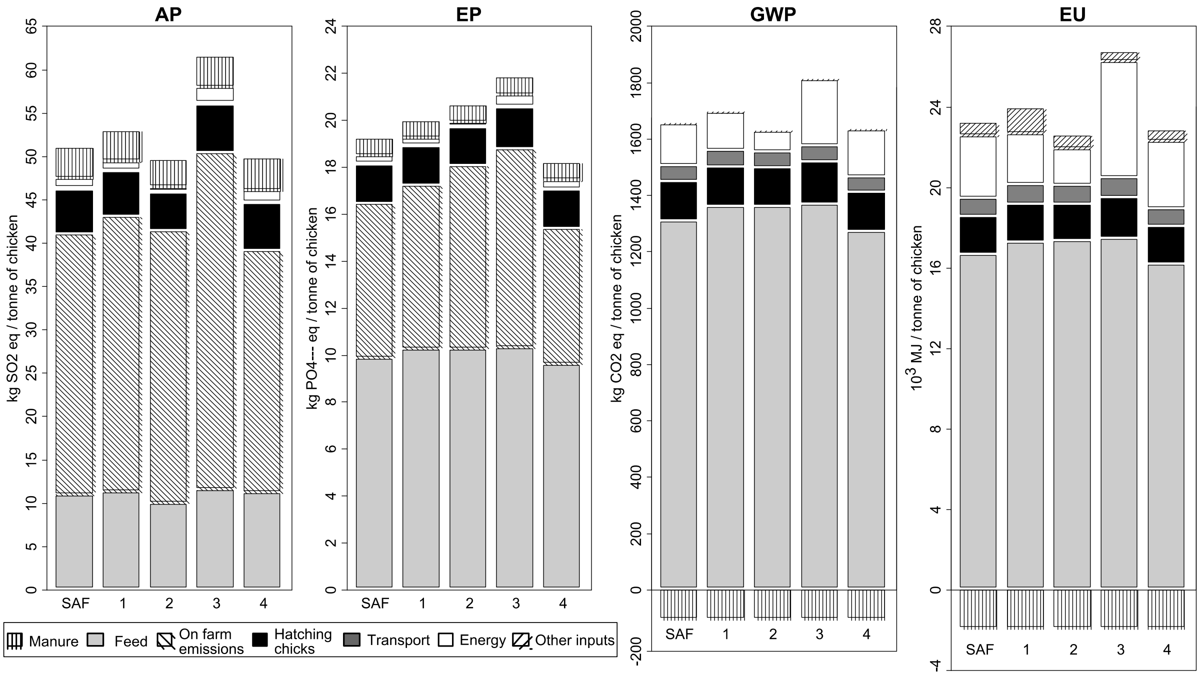


Figure 7: Life cycle impact assessment of one tonne of live weight broiler at the farm gate of each farm aggregated according to type and weighted by their relative contribution to the total chicken production of their type.
Impact categories are acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), and energy use (EU).

3.3. Analysis of improvement scenarios including farm diversity

Figure 8 shows the environmental impact for baseline scenario TEM and the three improvement scenarios (MOZ, FE, and AD) for the single average farm. Results are expressed in absolute values per impact category for one tonne of whole chicken packed ready for dispatch from the slaughterhouse. The figure underlines the high potential for progress in all the environmental impact categories and for all scenarios. Scenario MOZ predicted moderate reductions for acidification potential, global warming potential and energy use. Maritime transport causes acid pollution of the ocean so reducing transport distance for only one ingredient of the animal feed would reduce acidification potential by 3.4%. As expected, scenario FE allows the best decreases for all impact categories. Indeed, better feed conversion efficiency has a double effect as fewer crops would need to be produced and imported, and less ammonia volatilisation would occur in the building for a given level of production. Considering only on a small part of waste treatment, Scenario AD also helps reducing global warming potential and energy use with about 4.3% improvement due to avoided electricity consumption for incineration and energy production from waste anaerobic digestion.

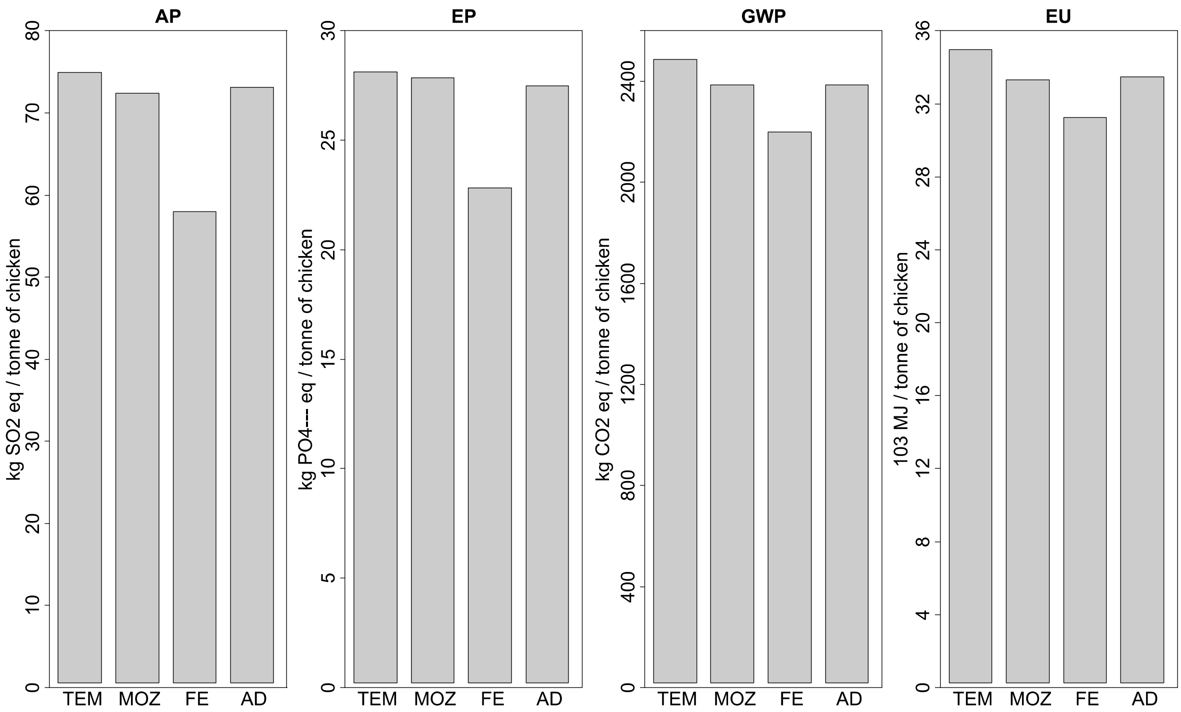


Figure 8: Life cycle impact assessment of one tonne of whole chicken packed ready for dispatch from the slaughterhouse for scenario TEM, MOZ, FE, and AD for the single average farm (SAF). Impact categories are acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), and energy use (EU).

Figure 9 shows the environmental impact reductions in scenario COM combining the three mitigation measures (MOZ, FE and AD, see section 2.2.1) with reference to the baseline scenario TEM. Results are expressed in absolute values per impact category for one tonne of whole chicken packed ready for dispatch from the slaughterhouse for the single average farm SAF and for each representative farm type (1 to 4). Compared to the baseline scenario TEM, the whole environmental impact reductions for the scenario combining all mitigation measures (COM) would be respectively 20.9%, 16.6%, 17.1% and 17% (i.e. -21 kg SO_{2eq}, -6 kg PO_4eq, 475 kg CO_2eq, -7.10^3MJ) for acidification potential, eutrophication potential, global warming potential and energy use (see results for the single average farm SAF).

The reductions at the pre-farm, on-farm, and post-farm stages are differentiated in the stacked bars. The pre-farm stage has the most significant impact mitigation for global warming potential and energy use due to avoided production and transport of feed (scenario FE) and reduction in the transport distance of maize (scenario MOZ). The on-farm stage largely improves acidification potential and eutrophication potential (scenario FE). The post-farm stage shows the same range of results than in Figure 8 because of absence of interaction with other scenarios (scenario AD).

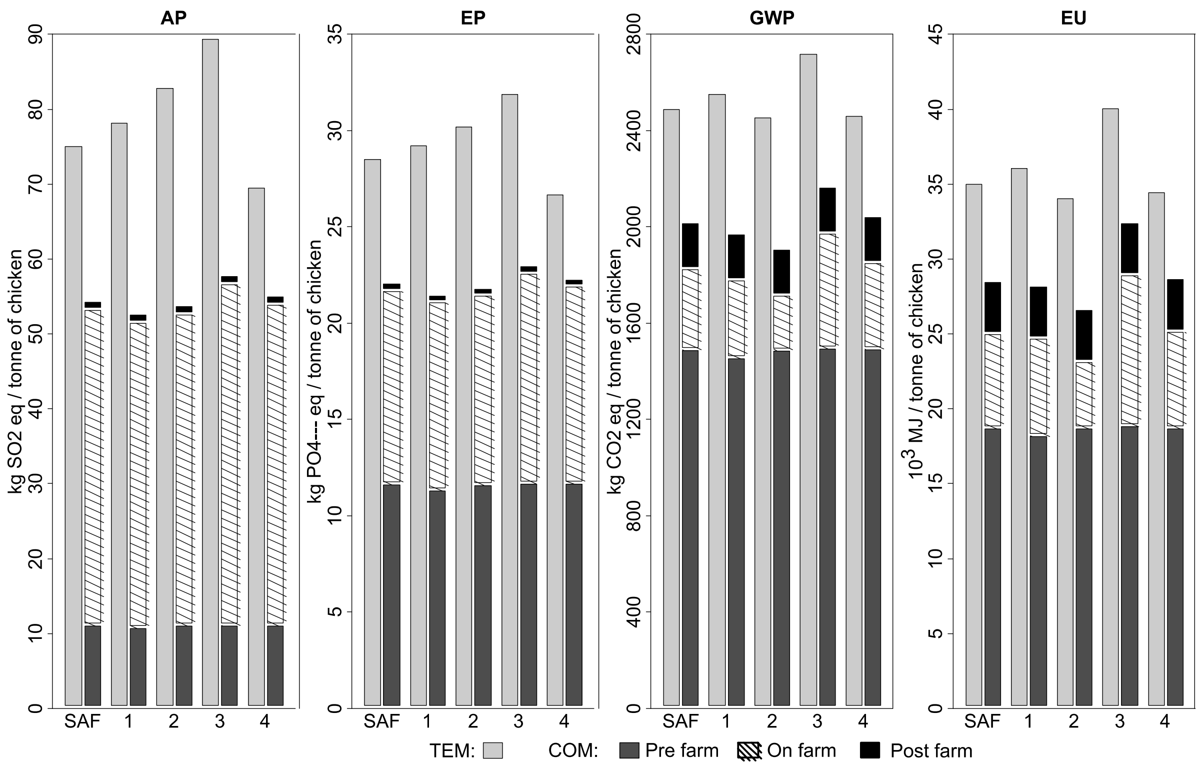


Figure 9: Environmental improvement of pre-farm, on-farm, and post-farm stages for one tonne of whole chicken packed ready for dispatch from the slaughterhouse for the single average farm (SAF) and each representative farm type (1 to 4) and for the baseline scenario TEM and the scenarios COM combining the three mitigation measures MOZ, FE and AD.
Impact categories are acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), and energy use (EU).

The distinction between the representative farm types mainly affects the results of the pre-farm and on-farm stages because the progress margin concerning these stages is closely linked to actual farm performances and the farm types are based on management practices that determine these farm performances. Type 4 farms are the most efficient. Potential environmental improvements are consequently limited for broilers produced on this type of farm. Nevertheless, scenario FE should not be overlooked because it is the most efficient mitigation scenario for Types 1, 2 and 3 which are responsible for 42% of the local broiler production.

Type 2 is of interest because it is the second contributor to local broiler production (22%, see Table 4) and also has a great improvement potential for the whole supply chain (+22% to +35% depending on the impact category). Type 3, which contributes the least to local production, has the highest improvement value for acidification potential and eutrophication potential (-32 kg SO_2eq and -9 kg PO_4eq) due to the high potential for improvement of feed conversion efficiency. These results underline the importance of considering both the technical performances of the farm types and their relative contribution to local production to better explain differences in the mitigation potentials associated with the scenarios and farm types.

4. Discussion

4.1. Insight into farm functioning to explain environmental impacts

The lack of specificity of results was successfully compensated for by introducing representative farm types in the life cycle inventory. Combining multivariate statistics with a LCA allowed us to better explain the relations between environmental impacts and the corresponding technical, structural and farm management characteristics, to improve the effectiveness of mitigation measures. Types 2 and 4 are the two most common types of farm currently encountered in Reunion Island (see Table 4). Type 2 farms have relatively old buildings with no dynamic ventilation system. In poultry farming, ensuring optimum indoor temperature is the best way to ensure high average daily weight gain and high feed conversion efficiency under tropical conditions. In terms of environmental impact, less dependence on energy reduces global warming potential and energy use, but less control of feed conversion efficiency increases acidification potential and eutrophication potential impact categories. Type 4 farms own more recent and better equipped buildings. These farms can achieve a better technical performance and particularly better feed conversion efficiency, which is highly negatively correlated with all environmental impacts. The two other groups correspond to more marginal situations. Type 1 farms are situated at low altitudes where temperatures are higher and face production problems due to sanitary incidents which affect all technical parameters. Low overall productivity mainly affects global warming potential and energy use. Type 3 farms are characterized by their high use of inputs. Their manual feeding system is probably responsible for the low feed conversion efficiency, consequently heightening all the environmental impacts.

These insights, which are not available with the first classical LCA, raise two issues. First with the objective of mitigation at the production stage, results link high environmental impacts with rundown buildings and lack of equipment. Second, results for Type 1 and 3 farms suggest that these farms are not representative of the actual supply chain in terms of the number of farms and their contribution to total local production as well as the high level of their technical and environmental performance. This raises the question of whether or not these types of farms with extreme characteristics should be included when building a single mean farm model, and more generally, do LCA studies need to systematically explore farm diversity to track unrepresentative farm types and then exclude them when building the single average farm model.

4.2. Reducing uncertainty

Table 5 presents the coefficient of variation for the mean of the single average farm and each representative farm type, i.e. the uncertainty of LCA results due to farm variability for either approach. The uncertainty analysis included the uncertainty of parameters used for the calculation of the NH_3 volatilisation rate (a major contributor to acidification potential and eutrophication potential).

For the first LCA based on a single average farm, results present a coefficient of variation from the mean of from 7.4% to 13.4%, depending on the impact category concerned. This variation is very close to the entire reduction resulting from combining all the mitigation measures, which is between 16.6% and 20.9% (see section 3.3). This limits conclusions to be drawn concerning potential environmental impact reductions.

When the farm types are distinguished, the coefficient of variation from the mean ranged from 4.5% to 11.4%, depending on the farm type and the impact category concerned. Including the resulting four farm models (representative of the four farm types) in the LCA significantly reduced the uncertainty of the results because the farm typology was built using two parameters (feed and energy consumption) that strongly affect the environmental impacts of poultry production. The contribution of parameters linked to feed conversion efficiency

(Quality score of building, Quality score of ventilation system, and Quality score of atmosphere control equipment) in the typology mainly enabled reduction of the uncertainty on acidification potential and eutrophication potential. The contribution of parameters linked to energy consumption (e.g. electricity consumption, fuel oil consumption) enabled reduction of the uncertainty on global warming potential and energy use impacts. The most common types, types 2 and 4, allowed the highest reduction in uncertainty of all the types because of their higher representativeness on the gradient observed on principal component 1 (See section 3.2.1). The decrease in uncertainty ranged from -36.9% to -44% for Type 2 and from -19.2% to -24.1% for Type 4, depending on the impact category concerned. The reduction in uncertainty was lower for Type 1 and Type 3 farms because these types are more variable, but this did not affect the conclusions because they represent only a small proportion of the farm population (13% and 7% respectively, see Table 4).

In our case study, distinguishing farm types led to a reduction in uncertainty from an average of 9.4% for the SAF approach to on average 6.4% (environmental impacts included) for the most representative types with the approach including a typology. Having an uncertainty below 10% and below environmental impact reductions associated with improvement measures (- 17.9% on average) makes the LCA results more meaningful for decision making. These results confirm the usefulness of including representative farm types when modelling the production stage to reduce the uncertainty of LCA results and to rank mitigation measures in order of priority for decision making based on LCA results.

Table 5: Coefficient of variation (%) of the mean of each type and of the all farm samples for the four environmental impacts at the slaughterhouse gate

Farm model	Single average farm	Representative farm type			
	(n=42)	1 (n=6)	2 (n=11)	3 (n=4)	4 (n=21)
Acidification potential	13.4%	11.3%	7.5%	11.1%	10.3%
Eutrophication potential	8.6%	7.3%	5.1%	7.6%	6.5%
Global warming potential	7.4%	6.7%	4.5%	7.8%	5.9%
Energy use	8.2%	8.1%	5.2%	7.6%	6.5%

Financial investments for mitigation measures are often limited in private companies particularly in the agricultural sector. For that reason, LCA results must provide information about where the most important, cost-limited and least risky reductions can be had. Scenarios MOZ and AD predict good results but require major organisational and financial investments, whereas FE significantly reduces environmental impacts (acidification potential, eutrophication potential, global warming potential) and use of resources (fossil energy, feed) mainly by changing rearing practices, and with limited financial investment (only modernising buildings on type 2 farms). Considering uncertainty analysis, and both environmental and economic aspects, the results of this study clearly show that the implementation of scenario FE should be a priority.

5. Conclusion

This study compared two life cycle inventory methods based on two farm modelling approaches: the first is a standard method based on a single average farm (one modelled farm intended to be representative of the actual farm population), and the second one based on a farm typology which distinguishes different average farms representative of each farm type (one modelled farm per farm type).

The two approaches have different purposes. The standard approach is time efficient if the objective is to highlight problem hotspots and identify promising mitigation measures. But the second approach, which combines a farm typology with the LCA, is better to explain variability of environmental impacts, reduce the uncertainty of results and make the right recommendations for the implementation of mitigation measures. Consequently, we recommend the systematic inclusion of farm typologies in LCA studies of agricultural products, especially when farm diversity is high, which is true in many soil-climatic conditions, for example in mountainous areas, and in many agricultural systems, for example small holder low-input farming systems.

Acknowledgements

This work was funded by *Crête d’Or Enterprise* and CIRAD. We are grateful to all the firms and farmers who contributed to the life cycle inventory.

Chapitre 2 – Chapitre 3

Lorsqu'une ACV est menée sur une filière agricole, la phase de production est généralement constituée de multiples unités correspondant aux exploitations ; c'est encore plus le cas lorsqu'une filière tend vers un contexte d'agriculture familiale. Cette caractéristique propre aux filières agricoles ne se retrouve pas ou peu pour des produits manufacturés plus classiques (p. ex. tee-shirt, bouteille PET) et peut avoir une incidence forte sur le résultat de l'analyse. Cette situation implique une approche méthodologique de l'étape d'inventaire de cycle de vie différente de la méthode classique.

Le chapitre 2 visait à étudier cette particularité méthodologique en proposant une façon nouvelle de gérer la question de l'incertitude dans l'application de la méthode ACV aux productions animales. La première analyse était basée sur un inventaire du cycle de vie dont la phase de production était modélisée par une ferme moyenne représentant l'ensemble des fermes de l'échantillon (moyenne des intrants pondérée par la production de chaque ferme). Les résultats de cette analyse montraient une incertitude sur les paramètres d'entrée de 6 à 9% ce qui ne nous permettait pas de conclure sur une différence significative entre les différents scénarios d'amélioration comparés. Cette incertitude a pu être en partie maitrisée en couplant l'inventaire du cycle de vie à une analyse typologique basée sur des critères de niveau d'équipement des bâtiments et de pratiques des éleveurs. Plusieurs groupes d'exploitations significativement différents ont ainsi pu être mis en évidence. Ces nouveaux résultats ont permis d'éliminer les exploitations atypiques de l'inventaire du cycle de vie, et de fournir des recommandations plus spécifiques concernant les scénarios d'amélioration pour les groupes d'exploitations identifiés.

Au cours de cette évaluation environnementale, nous nous sommes heurtés à un autre problème, récurrent en ACV sur les productions animales, celui de l'allocation des coproduits et en particulier des effluents d'élevage (Audsley *et al.*, 1997). En effet, en fonction de la région, du système, voire même de l'exploitation étudiée, les effluents peuvent être considérés comme un déchet, comme un coproduit ou encore comme le produit principal dans certains pays (Fleming *et al.*, 1998; Blanchard *et al.*, 2013). Ces effluents peuvent donc être achetés, vendus ou échangés, ce qui complexifie la prise en compte du « fardeau environnemental » qui lui est associé. Dans une communication présentée au congrès « *Life Cycle Assessment in the Agri-Food Sector* » de Saint Malo en 2012 (cf. Appendice 5), nous avons comparé les résultats de l'utilisation de différentes méthodes d'allocation des coproduits: extension des frontières du système, allocation massique, économique et azotée, appliquées sur le même inventaire du cycle de vie. Dans un système donné, les résultats montrent que le choix de la méthode d'allocation des coproduits peut avoir une influence non-négligeable sur les scores des catégories d'impact. Le choix de la méthode d'allocation des coproduits est largement dépendant du contexte de production. Une attention particulière est requise lors de l'intégration de cette méthode dans un cadre d'évaluation plus général.

Ces deux particularités méthodologiques relevées soulignent le fait que l'application de la méthode ACV aux systèmes d'élevage en vue d'aider à la décision requiert un degré de connaissance supplémentaire sur le fonctionnement des systèmes étudiés par rapport aux produits plus classiquement évalués.

Bien que l'ACV soit une méthode normée (ISO 14040), elle reste assez flexible pour être remobilisée sur d'autres systèmes qu'un produit ou un service. On retrouve en effet la méthode ACV à la base de plusieurs méthodes d'évaluation plus globales (p. ex. l'empreinte écologique) où le système étudié est un système plus large tel qu'une filière (Elghali *et al.*, 2007), un territoire (Loiseau *et al.*, 2012), ou même un pays (Rees, 1992). Son utilisation implique dans notre cas un changement de système, d'un système de type *produit* vers un système de type *filière*. La définition que peut prendre la notion de *filière* étant relativement variable, ce changement d'échelle demande de correctement délimiter les frontières du système étudié afin d'explicitement indiquer ce qui est pris en compte dans l'analyse. La méthode ACV est également assez flexible pour pouvoir spatialiser les flux de matière en séparant les sites de consommation et les sites d'émissions par zone géographique, et donc évaluer spécifiquement sur quel territoire vont être générés les impacts. Dans notre cas, cette spatialisation demande de vérifier les arbres de processus des produits de chaque fournisseur identifié sur le territoire afin de vérifier l'origine de tous ses intrants. Enfin, il est possible de convertir une partie des flux matériels (les intrants, les déchets et parfois les émissions) en flux économiques dans l'étape d'inventaire du cycle de vie. Ce type de conversion se retrouve dans différentes utilisations dérivées de l'ACV environnementale comme les méthodes de *life cycle costing* (Swarr et al., 2011) et l'ACV *hybride Input output* (Lenzen, 2002). Lors de cette conversion, la variabilité des prix des matières premières impose cependant que l'inventaire de cycle de vie soit réalisé la même année que le référentiel de prix utilisé.

La méthode ACV répond aux trois critères de compatibilité fixés précédemment. Cette méthode se pose donc comme la méthode de choix pour évaluer les impacts des activités de la filière sur les parties prenantes du système écologique définies dans le cadre conceptuel (Chapitre 1§4.2).

Dans le chapitre suivant, nous explorons les particularités méthodologiques d'une analyse coût-bénéfice, la méthode des effets, partiellement menée sur notre cas d'étude. Classiquement utilisée pour l'évaluation de projet, nous réutilisons une partie de sa méthodologie pour caractériser les emplois créés suite à une augmentation de la demande intérieure en produit de volaille.

Chapitre 3

Social sustainability of agricultural supply chains – a case study on the effect of local poultry output on employment across different regions

Submitted *in Journal of Cleaner Production*

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Abstract

In a context of globalisation and increased competition between agricultural supply chains, local industries are more than ever obliged to demonstrate the extent of their contribution to sustainable development in their region. While the methods for assessing the environmental impact of products are now fairly well developed, methodological advances in the assessment of social impacts remain inadequate. In this study, we present an approach to assessing the contribution made by one agricultural supply chain to the social sustainability of a region. The case study concerns the main supply chain of poultry products to Reunion Island. Following a strategic review of the issues of the region in question, and those of the local poultry supply chain, employment was identified as the most relevant economic indicator of social sustainability. The direct, indirect and induced jobs generated inside and outside the region were quantified using input-output analysis. Its implementation in the baseline year (2010) is used to assess the supply chain's degree of integration in the regional economy and in particular its dependence on grain inputs imported from France. The multiplier effects on induced employment highlight an important supportive role of the supply chain for communities in rural areas. The method was also used to compare the impact on employment of two scenarios concerning market share evolution in the supply of poultry to Reunion over a period of ten years. The linking of strategic planning analysis with the indicators produced by the method proposed (jobs created by geographical area and socio-professional category, and the effect of induction) complements the overview of the multi-faceted role played by agricultural supply chains in the social sustainability of the region. Specific indicators such as jobs created per capita or per kilogram of produce could provide agricultural supply chains with new arguments to justify their social importance. The main obstacle to factoring outcomes into the decision-making processes of local industries is the identification of the players genuinely affected by changes in market share. The method offers a selection criterion based on the importance of turnover to minimise uncertainty for the suppliers potentially most affected. Theories borrowed from strategic business management, such as the theory

of resource dependence, will in future enable decision-makers to take greater account of the key players, whether they are connected to the supply chain through economic flows (suppliers) or not (competitors, community).

Keywords**:** Social sustainability; Input output analysis, Broiler supply chain; Reunion Island

1. Introduction

In the current context of globalisation, the issue of the regionalisation of sustainable development is exacerbated by the relocation of firms seeking ever lower production costs. This is even truer of the agricultural sector, which for reasons of traceability and quality, is experiencing strong demand for the relocation of its production systems around consumers (Feagan, 2007). This demand is also accompanied by a growing concern about the impact of agriculture on the environment and health. The movement of these sectors towards a more sustainable state has been extensively studied in terms of environmental sustainability in recent years (Payraudeau and van der Werf, 2005). This awareness is now resulting in better identification and integration of these objectives in current policies (Barber *et al.*, 2012; Podhora *et al.*, 2013). However, the aim of solving environmental problems will not in and of itself achieve sustainability, as such efforts will inevitably be undermined by social imbalances (Campbell, 1996). While it is generally accepted that the agricultural sector plays a wider role than just food security, such as the provision of socio-economic services (Cairol *et al.*, 2009; Hediger and Knickel, 2009; Thompson, 1986), few studies characterise these services in terms of benefits for the social sustainability of the regions. This situation is partly due to the difficulty in defining the concept of social sustainability and the goals with which it is associated in the broader field of sustainable development (Littig and Griessler, 2005). Faced with this lack of conceptual framework, a substantial body of literature in various disciplines has emerged over the past decade in an attempt to better delineate this notion (Boström, 2012). The components identified as fundamental to social sustainability in the literature are access to basic well-being needs, equity, integration and social cohesion (Åhman, 2013; Murphy, 2012). The selection of a set of indicators among these components, however, depends largely on the sociocultural priorities of the social system in the region under study. It is therefore unlikely that a consensus that is uniformly applicable from one region to another will be found (Theys, 2002). Agriculture is a perfect illustration of this last observation, given the diversity of environments, natural resources and social organisations that it mobilises from one region to another. The transposition of these basic components to the level of regional issues and their articulation in the operational field of the agricultural supply chains constitutes a major challenge to the progress of research into social sustainability.

One of the main secondary roles attributed to the agricultural sector is assuring the viability of rural areas enabled, amongst other things, by maintaining employment (Cairol *et al.*, 2009;

Hediger and Knickel, 2009). Rather classically evaluated in terms of public economy calculation, but poorly understood in the context of regional social sustainability, the creation of employment and remuneration for work are nevertheless key elements of the basic components of social sustainability. In the first instance, remuneration for work allows access to basic well-being needs (Rogers *et al.*, 2012). Well-being is now accepted as a multidimensional notion, including emotional and physical aspects that go way beyond simple income. But in societies with strong social inequalities, the search for equity between individuals, which is enabled in part through access to employment, is a critical priority.

Graham and Felton (2007) show that the reduction of inequalities in wealth redistribution has a greater positive impact on the achievement of overall well-being than an overall increase in revenue. In addition to this material dimension, labour in its broadest sense is a factor in social integration. It occupies an important place in societies due to the psychological role it plays and the psychosocial functions involved in the integration of individuals (Littig and Griessler, 2005). Within societies, the creation of employment allows an easing of tensions through the reduction of inequality and social exclusion – an important factor in the loss of stability and social cohesion (Åhman, 2013). At the regional level, the agricultural sector is the main economic player outside the cities in ensuring the sustainability and social cohesion of communities active in the production of goods and services that supply them but also all secondary activities related to household consumption (Scott *et al.*, 2000). Maintaining employment allows both local service to be assured for businesses and also limits migration and slows urban congestion. The development of a method for the characterisation of employment in a region for feeding into the conceptual framework of social sustainability is therefore of great interest to policy-makers in local authorities and sectoral policies.

Employment in economic evaluation is typically estimated using input-output analysis. Built in to methods such as cost-benefit analysis, it enables the measurement of employment. The effects method, developed by Charles Prou and Marc Chervel in the 1970s (Chervel and Le Gall, 1976), has often been used in France and in developing countries to assess scenarios used for decision-making in various sectors (Chervel, 1992). This method is particularly useful for calculating the economic profitability of investment projects because it takes account of the meso- and macroeconomic constraints and objectives. From the value-added generated by the project, it is possible to infer the indirect effects on employment in different sectors of the economy. In a second phase, the calculation of jobs related to the expenditure of those in direct and indirect jobs enables to evaluate the induction effect on employment in the community. Such methods of economic evaluation have been repeatedly articulated in fields other than public economic calculation, for example in the environmental assessment of roads projects (Martin and Point, 2012) or in social life cycle assessment (Lagarde and Macombe, 2013).

This article sets out to suggest a method based on these economic valuation methods and to assess the contribution of an agricultural supply chain to the social sustainability of its region in terms of distribution of income and employment. The illustration is based on a case study, the poultry industry in Reunion, a tropical island in the Indian Ocean. Various scenarios featuring changes in market share in this sector are simulated to obtain a dynamic result of the calculated effects and thus generate a more detailed analysis. The study focuses on jobs in this island region and in France. The discussion of the article focuses on the benefits of the method in terms of decision-making support for local authority policy-makers vis-à-vis the management of food supply sources and in providing figures which can be used by agricultural supply chains in promoting their social image.

2. Materials and Methods

2.1. Strategic analysis of the region

The global context of trade liberalisation, including agricultural commodities, makes difficult to maintain production activities in certain regions. This certainly applies to the animal production sectors on Reunion Island, a French overseas department in the Indian Ocean. The major poultry supply chain for example is facing strong competition from imported frozen goods and is struggling to justify the social importance of its regional presence to policy-makers and consumers. To face this type of local issue, the conventionally-used sustainable development indicators (i.e. growth rate of GDP per capita) are overly generic and therefore unable to provide operational solutions in line with the reality of development players (Hospido *et al.*, 2009; Walter *et al.*, 2011; Wood and Garnett, 2010). Rather than transposing global issues to a more local level, the emergence of solutions requires the representation of these issues by the 'mediation of strategic interpretation' of the region, as Godard (1997) puts it. This mediation is particularly important for assessing social sustainability given the heterogeneity of the social issues from one region to another (Theys, 2002). This heterogeneity is the result of the issues of identity (history and conflicts), geography (location on the globe), and material factors (availability of renewable and non-renewable resources) specific to each region (Laganier Richard *et al.*, 2002). In order to identify the relevant indicators with which to assess the social sustainability of the supply chain, a strategic analysis of the issues of Reunion Island and the industry was conducted prior to the study. The objective of this step was to highlight the critical points where the region most needs to advance and on which the sector has a lever for action. Reunion Island is governed by the same administration as mainland France. For the remainder of the text, mainland France will be referred to simply as 'France' and the overseas department of Reunion Island as 'Reunion'. The realisation of this strategic review has highlighted the influence of two particular situational contexts in relation to France (L. Ploquin, 2011). The first concerns the market for poultry meat. The French poultry industry promotes poultry fillets on the domestic market because of the eating habits and high standard of living of its consumers (FranceAgriMer, 2012). The discarded parts of the chicken are subsidised and exported to demanding markets such as Saudi Arabia and Reunion (DGDDI, 2007). These exports are at competitive prices in the international market but above those which the sector could have charged in the mainland France domestic market. In Reunion however, the domestic market demands products at low prices because of the lower standard of living of the population. However, Reunion's production chains incur the same production costs (labour and taxation) as France but with a lower capacity for commercialisation of the whole chicken. The competitive environment is seen as akin to the import surges experienced by West Africa in the 1990s (Sharma *et al.*, 2005) as well as more current situations where countries such as China and South Africa have resorted to anti-dumping measures against the United States and Brazil (WTO Decisions, 2010, 2012).

The second feature of the economic environment in Reunion concerns the standard of living of the population. The region is experiencing a particularly critical unemployment rate: in 2011, 29.5% of the workforce was unemployed as against 9% in France (INSEE, 2011). In most rural areas, unemployment among those aged 15 to 64 rises to over 40%. This can be explained by a rapid and insufficiently anticipated transition from an economy predominantly based on agricultural income (67% of the workforce in 1946) to one which is today dominated by the tertiary sector (85% of the labour force in 2011). Strong demographic growth, the entry of women into the labour market and the increase in productivity with poor job creation potential explain the rise in unemployment during this period (AFD *et al.*, 2004). Many inequalities and social problems can be linked to this high level of unemployment, whether in terms of health, leading to greater numbers of risk profiles (e.g. diabetes, obesity, alcoholism, etc.), education (e.g. illiteracy) or social exclusion (e.g. family break-up, loss of housing) (Temporal, 2006). The fight against unemployment is therefore a major social issue in Reunion. The job creation indicator is therefore important in assessing the contribution of the poultry supply chain to the social sustainability of the region.

2.2. Evaluation of jobs generated

To assess the contribution of a supply chain to the regional economy of an area, some steps of the effects method were used (Chervel *et al.*, 1997). The steps of this method of particular interest to us are those that allow the breakdown of increased local production in the production- trading accounts of all the firms ahead of a project to calculate the embedded value-added and the embedded imports related to the generated variations in final production. This can be done in two ways:

1 - By manually ascending the chain. Starting from the agent carrying out the final processing of the end product and then climbing the customer-supplier chain, the value-added by each agent is obtained by studying the production-trading account.

2 - By using the input-output table. This table, developed in France by the National Institute of Statistics and Economic Studies, gives an overview of national or regional accounting for overseas departments. The accounts are grouped into four sub-tables: the product supply table, the intermediate use table, the final uses table and the generation of income by industry table. The intermediate use table, the core of the national account system, built on the foundations of the multi-sectoral analysis of Leontief (1936), outlines the interdependence between sectors and the technical relationships between different manufactures of produced inputs. The input-output table as presented does not allow for the disaggregation of the domestic inputs and imported inputs for each sector. A new table, known as the spreadsheet of embedded rates (see Appendice 3: Input-Output Analysis), is deduced from the input-output table, which can be used to calculate increases in domestic value-added and intermediate imports for each sector when an increase in final demand occurs (Chervel *et al.*, 1997).

As the input-output table is an aggregation of all national firms' accounts, some uncertainty persists concerning the values that have emerged. Ascending manually the chain should be promoted to minimise these uncertainties. However when the amounts treated in the final product are negligible or when production-trading accounts are not available, the remainder of the value of intermediate consumption is broken down into embedded value-added and embedded imports in the spreadsheet of embedded rates. The amounts of these intermediate inputs are pre-sorted by origin and by sector and combine all the production accounts of the surveyed agents in a single consolidated account (Chervel *et al.*, 1997).

2.3. Definition of the System

The system studied is that of the supply of all poultry species (i.e. chicken, turkey and guinea fowl) and preparations (whole, cut, processed) combined in Reunion. The data required for the analysis (accounts, input-output table, surveys) were collected for the year 2007. In that year, the import sector provided 59.2% of the volume of domestic demand for poultry meat. The main local poultry supply chain supplied 26.3%. The remaining 14.5% corresponded to an estimate of direct sales and two independent firms, which marketed their products using different retail channels from the import sector and the main local supply chain. For simplification purposes, these were not included in the study in order to more clearly illustrate the proposed method. The analysis focuses on the assessment of the embedded and induced effects of the activity of agents in the main local production chain and all its suppliers of goods and services under different market share distribution scenarios. These players are involved in an inter-professional association involving all stakeholders in the meat supply production-marketing chain in Reunion. The system under study is divided into two subsystems stemming from the technique used to break down the increase in domestic demand: manually ascending the supply chain or the spreadsheet of embedded rates (see section 2.2). This division gives rise to two levels of precision: the *core* and the *environment* of the supply chain (see Figure 10). The final marketed product is a kilogram of poultry meat born, raised, slaughtered and processed in the Reunion poultry supply chain. Starting from the agent through whom the final product is delivered, the marketing unit of the slaughterhouse, and climbing back up the customer-supplier chain, each supplier or agent is divided between the two subsystems according to the following cut-off rule: i) the *core* of the supply chain includes all suppliers that produce more than 20% of their turnover in the upstream business. This rate is a threshold value based on which the customer-supplier relationship can be considered strong (Perrotin and de Brugière, 2007) and where more complex coordination mechanisms must be established between the two players (Boons *et al.*, 2012). And ii) the *environment* of the supply chain includes all other agents. A small proportion of inputs is bought outside Reunion or France and for the purposes of simplification is excluded from the analysis. The inclusion of an agent in the *core* subsystem gives rise to a study of his production-trading account and therefore a high level of accuracy on jobs generated by this agent. After applying the cut-off rule, the main subsystem obtained, the *core*, typically extends to agents through whose hands the final product transits and/or is processed in the region: the feed producers, the hatchery, the breeders' cooperative, the poultry breeders, the slaughterhouse and the marketing unit for processed products. The *environment* of the supply chain includes the rest of the suppliers, the most important of which are transportation, incineration units and distributors of packaging and pallets.

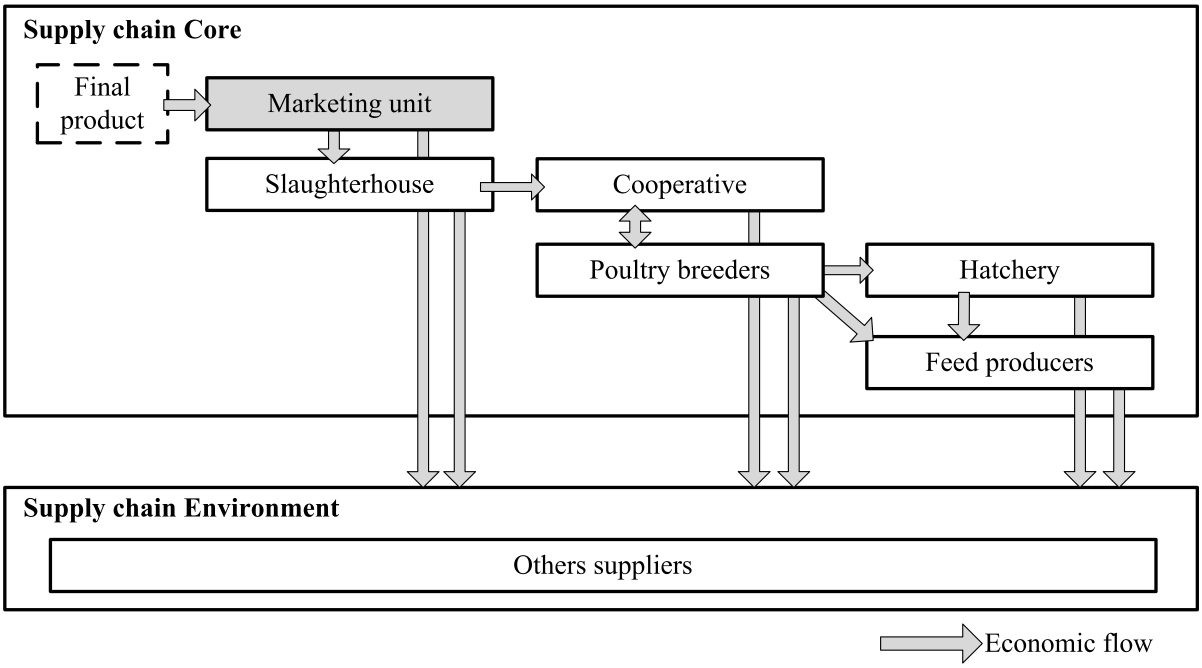


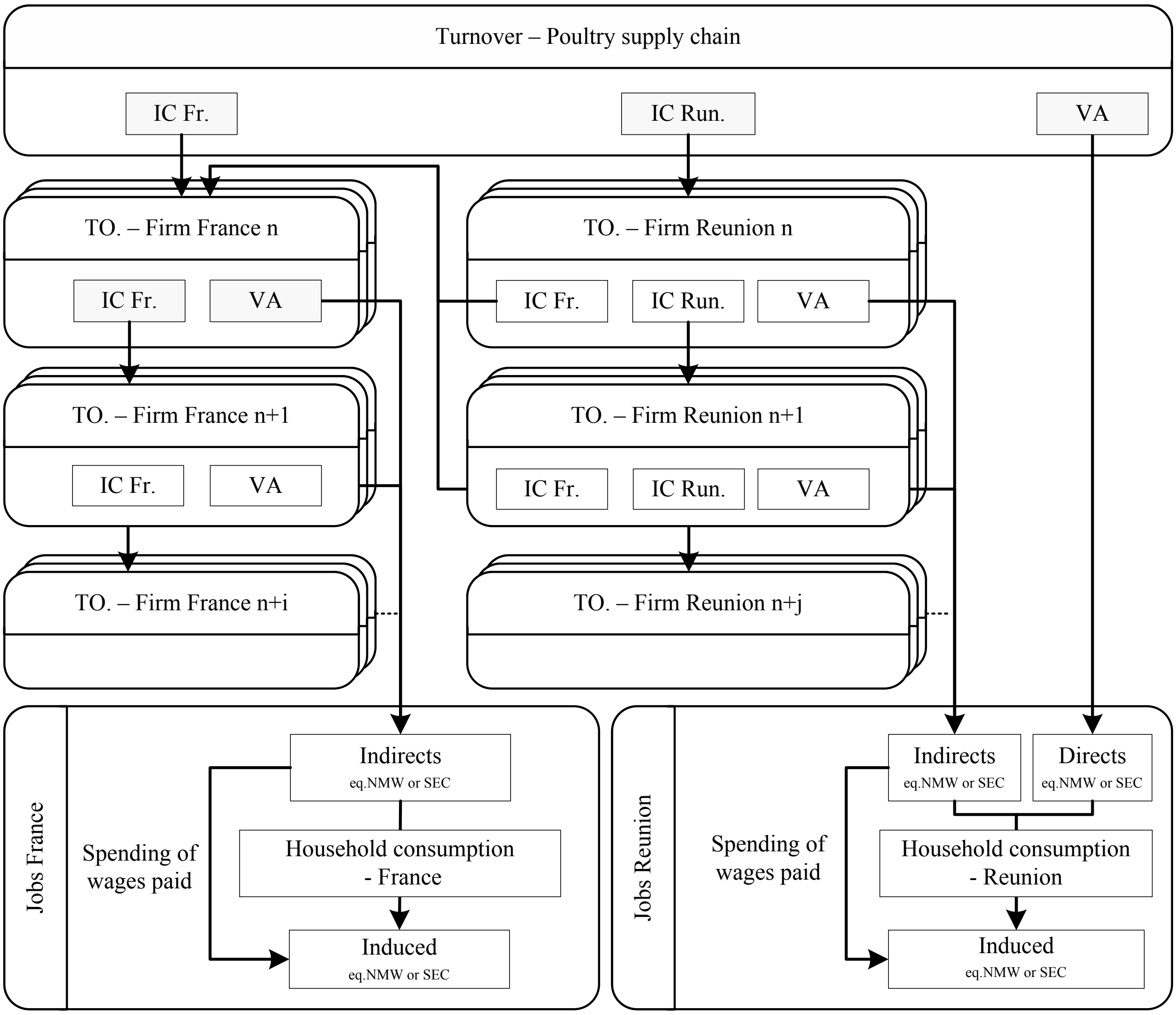
Figure 10: Definition of the system studied starting from the company marketing the final product (in grey) and up the customer-supplier chain via the economic flows.

2.4. Calculation of jobs embedded

Gross wages are obtained either directly in the trading account or social balance sheet of firms in the *core* subsystem, or indirectly through the transformed the input-output table for agents in the *environment* subsystem. From this, the number of 'direct' and 'indirect' jobs can be deduced. To calculate the indirect jobs generated in France by the activity of the sector in Reunion, the intermediate consumption of imported goods of French origin in the *core* subsystem and the intermediate imports from the breakdown of locally purchased intermediate consumption are added up and then broken down in the spreadsheet of embedded rates obtained from the transformation of the input-output table of the French economy. The input-output tables obtained from the INSEE for Reunion and France use the nomenclature NES 1994-2007 and cover 24 sectors (INSEE, 2010c, 2010a).

A third type of employment, known as 'induced' employment is calculated based on the salary expenditure (i.e. household consumption) of direct and indirect jobs, taking account of the socio-professional category. Similar to the calculation of indirect jobs, induced jobs are obtained by breaking down the spreadsheet of embedded rates of household consumption disaggregated by sector. The induction effect can be deduced from this result, calculated by dividing the cumulative effect (induced employment) by the direct and indirect effects caused by the demand. In this second phase, we only take into account of the increased household consumption and not the use of the operating surplus by firms. For simplification purposes, we also suppose that the marginal propensity to consume and the return to scale are fixed.

Household consumption by socio-professional category is obtained by the INSEE 'Family Budget' survey conducted in Reunion and in France in 2006, adjusted for inflation (INSEE, 2007, 2010b). The direct, indirect and induced effects calculated are divided by socio-professional category (level 1 - 8 items) according to the PCS-ESE 2003 (INSEE, 2003) classification or equivalent gross national minimum wage (eq.NMW). Gross wages and distribution by socio-professional categories for direct jobs were obtained by the firm's social balance sheet. The gross wages of socio-professional categories by sector and the distribution of socio-professional categories by sector for indirect and induced jobs were obtained from the INSEE 'Continuous Employment' survey (INSEE, 2008). The gross national minimum wage is the hourly, monthly or annual minimum wage before social contributions that an employer is legally obligated to pay its employees. In France, since the national minimum wage was revised upwards on 1 July, an average gross national minimum wage of € 15,206 was calculated for the periods 2006-2007 and 2007-2008. The knock-on effects related to an increase in final demand on these three types of employment are shown in Figure 11.



TO. : Turnover, IC : Intermediate consumption, VA : Value-Added, eq.NMW: National Minimum Wage equivalent job, SEC: Socio-economic Classification

Figure 11: Diagrammatic representation of the calculation of jobs in Reunion and France.

2.5. Definition of scenarios explored

In this study, we want to estimate the number of jobs generated by the activity of the Reunion poultry supply chain under various scenarios of changes in market share distribution between this supply chain and the import sector between 2010 and 2020. The distribution of market share between the year of data collection in 2007, and the simulation baseline year in 2010, is known. Domestic demand for poultry meat for the period 2010-2020 was estimated based on two trends impacting on this demand: i) population growth, estimated for this period at 11.3% by INSEE (2010d). ii) in 2007, the average annual consumption of poultry meat of 32 kg per capita had increased by about 1% per year over the previous five years. This trend is replicated for the projection period. The increase in domestic demand for poultry meat linked to these estimates will create new market share which may be acquired by the two sectors. Since 2010, however, consumers have had access to poultry meat from the local poultry supply chain that is almost as competitive as the frozen meat from the import sector thanks to a State subsidy on the final product price. For 15 years, the productivity of local supply chain was limited only by its ability to introduce new breeders (+6.6 % per year in volume). Since the 2007 food crisis, the industry has become less competitive against imported frozen products and production volumes have stagnated at about + 1% per year. Here we have chosen to simulate two extreme scenarios whereby 0 or 100% of consumers respond positively to this incentive.

In the reference scenario (REF), we assume that consumers are indifferent to this incentive and maintain their buying habits. The local supply chain posts the same growth as in previous years and the remaining market share is newly available to the import sector. The volume growth of poultry meat sold by the local supply chain is about +1.1% per year (+ 11.5% over 10 years, i.e. 1,000 additional tons) corresponding to the average annual growth between 2006 and 2010.

In the local scenario (LOC), consumers favour local purchase and newly available market share goes exclusively to the local supply chain. The volume growth in the local supply chain is about +5.5% per year (+70.4% over 10 years, i.e. 6,100 tons more), corresponding to the total production of the additional volumes of domestic demand.

All projection assumptions are shown in Table 6.

To simulate the increase of local production, the value of the intermediate consumption of all agents in the *core* subsystem is increased in linear fashion based on the percentage growth of this additional production. Plans to hire and install breeders, allowing an estimate of the evolution of direct jobs for each scenario, were obtained by a survey conducted with these agents. A share of the production of certain agents is sold outside the inter-professional association (e.g. production of chicks) or outside the poultry industry (e.g. production of concentrated feed). The value of intermediate consumption is then reduced by the proportion of their turnover outside the supply chain.

Table 6: Observation and estimation of the poultry market in Reunion for REF and LOC scenarios between 2007 and 2020.

	Observed data				Scenario	Estimated data					Evolution
Year	2007	2008	2009	2010		2011	2012	…	2019	2020	2010-2020
Population (10^3 hab.)	794	804	814	824		834	844	…	909	918	11.3%
Poultry demand (10^3 tonnes/year)	23.4	23.9	25.4	26.6		27.2	27.8	…	32.1	32.7	23.0%
Poultry consumption (kg/year/capita)	29.4	29.7	31.2	32.3		32.6	32.9	…	35.3	35.7	10.5%
Importations sales (10^3 tonnes/year)	14.7	15.3	16.9	17.9	REF	18.4	18.9	…	22.5	23.0	28.6%
					LOC	17.9	17.9	…	17.9	17.9	0.0%
Local poultry sales (10^3 tonnes/year)	8.7	8.6	8.5	8.7	REF	8.8	8.9	…	9.6	9.7	11.5%
					LOC	9.3	9.9	…	14.2	14.8	70.4%

3. Results

3.1. Employment generated by the sector in 2010

Table 7 shows the geographical distribution of jobs generated by the activity of the sector in direct, indirect and induced NMW equivalent jobs between Reunion and France for the reference year 2010. As all firms in the *core* system are in Reunion, all direct jobs were located on the region. The indirect jobs are mostly located in Reunion (71%). Meanwhile, jobs induced by household consumption are in turn based on the location of direct and indirect jobs and therefore also mainly generated in Reunion (87%).

Table 7: Geographical distribution of employment generated by the activity of the supply chain in 2010 between France and Reunion.

	Geographic distribution		
	Reunion Island	France	Total
Direct Employment	100%	-	100%
Indirect Employment	71%	29%	100%
Induced Employment	87%	13%	100%

Table 8 shows the distribution by type (direct, indirect, and induced) of NMW equivalent jobs generated by the activity of the supply chain in Reunion and France for the baseline year 2010. Direct employment accounted for 51% of the types of jobs in Reunion. For 1,000 tons of poultry produced, 98 direct NMW equivalent jobs, 39 indirect NMW equivalent jobs and 53 induced NMW equivalent jobs were generated upstream and downstream of the production farm. The induction effect evaluated by the employment multiplier is 0.39 for Reunion and 0.51 for France.

Table 8: Breakdown per type of employment generated in Reunion and France in 2010.

	Type of employment distribution	
	Reunion Island	France
Direct Employment	51%	0%
Indirect Employment	20%	65%
Induced Employment	28%	35%
Total	100%	100%

The breakdown by sector of direct, indirect and induced employment generated by the activity of the poultry supply chain in 2010 is shown in Table 9. Direct employment in Reunion was distributed mainly in two sectors. 45% of jobs were in the *Agriculture, forestry and fishing* sector, i.e. the activities of chick production (breeding, spawning, and hatchery), poultry breeding and technical support. 47% of jobs were in the *Processing and preserving of meat and production of meat products* sector i.e. the slaughterhouse and its marketing unit. Nearly half of indirect jobs in Reunion were generated in the *Office support, and other business support activities* (44%), 15% in the *Transportation and storage* sector and 10% in the *Wholesale and retail trade* sector. For France, the sectors that benefited from the activity of the sector in terms of indirect jobs were those of *Agriculture, forestry and fishing* (27%), *Transportation and storage* (18%), and *Manufacture of machinery and equipment* (14%). Induced jobs generated by household consumption were mainly in the sectors of *Wholesale and retail trade* and *Financial and insurance activities* in Reunion and France.

Table 9: Distribution of jobs generated by economic sector in Reunion and France in 2010.

Direct employment			
Reunion Island			
Agriculture, forestry and fishing	45%		
Processing and preserving of meat and production of meat products	47%		
Other agribusiness	8%		
Indirect employment			
Reunion Island		**France**	
Office support, and other business support activities	44%	Agriculture, forestry and fishing	27%
Transportation and storage	15%	Transportation and storage	18%
Wholesale and retail trade	11%	Manufacture of machinery and equipment	14%
Electricity, gas and water	8%	Other manufacturing	16%
Other activities	23%	Other activities	0%
Induced employment			
Reunion Island		**France**	
Wholesale and retail trade	77%	Wholesale and retail trade	39%
Accommodation and food service activities	5%	Financial and insurance activities	13%
Financial and insurance activities	5%	Accommodation and food service activities	10%
Personal service activities	5%	Personal service activities	9%
Other activities	9%	Other activities	29%

The breakdown by socio-professional category of direct and indirect jobs in NMW equivalent jobs generated by the activity of the poultry supply chain and the induced employment generated by household consumption is presented in Table 10. The observed distributions are based on the representation of sectors for each type of job. Dominated by the agricultural and agro-industrial sectors, more than half of the direct jobs in Reunion (54%) were blue-collar jobs, and a little less than a third intermediate jobs (30%). The upper management and white collar categories were fairly poorly represented (7% and 9% respectively). Indirect jobs in Reunion, mainly in the service industries, were divided almost equally between the following categories: intermediate occupation, white and blue collar (between 23 and 34% depending on the category). The upper management category represented a significant part with about 16% of employment. Indirect jobs in France, however, were rather dominated by intermediate professions and blue collars, while the upper management category was poorly represented (7%). Breakdowns by socio-professional category of induced jobs between Reunion and France were much the same. The white collar category was better represented in Reunion and in France (34% and 33%) than the blue collar category (17% and 15%).

Table 10: Distribution of jobs generated by socio-professional category in Reunion and France in 2010.

	Direct Employment	Indirect Employment		Induced Employment	
	Reunion Island	Reunion Island	France	Reunion Island	France
Upper level executive	7%	17%	8%	14%	19%
Mid-level executive & liberal professions	30%	33%	38%	35%	33%
White collar	9%	27%	15%	34%	33%
Blue collar	54%	23%	39%	17%	15%

3.2. Forecast and evolution in employment generated by the sector by 2020

The evolution of total employment generated by the activity of the local supply chain in NMW equivalent jobs in Reunion and in France in the REF and LOC scenarios is shown in Figure 12. For the LOC scenario, there is a 41% growth in total jobs and 15% for the scenario REF. The decrease in the slope of the curve between the years 2012 and 2016 is explained by a decrease in hiring planned for this period. As a significant hiring phase occurred over the period 2007-2010, the increase in production volumes will require the hiring of only a few workers over the period 2012-2016. As the increase in the value of intermediate consumption is linear, we did not observe any changes in the distribution by sector and socio-professional category.

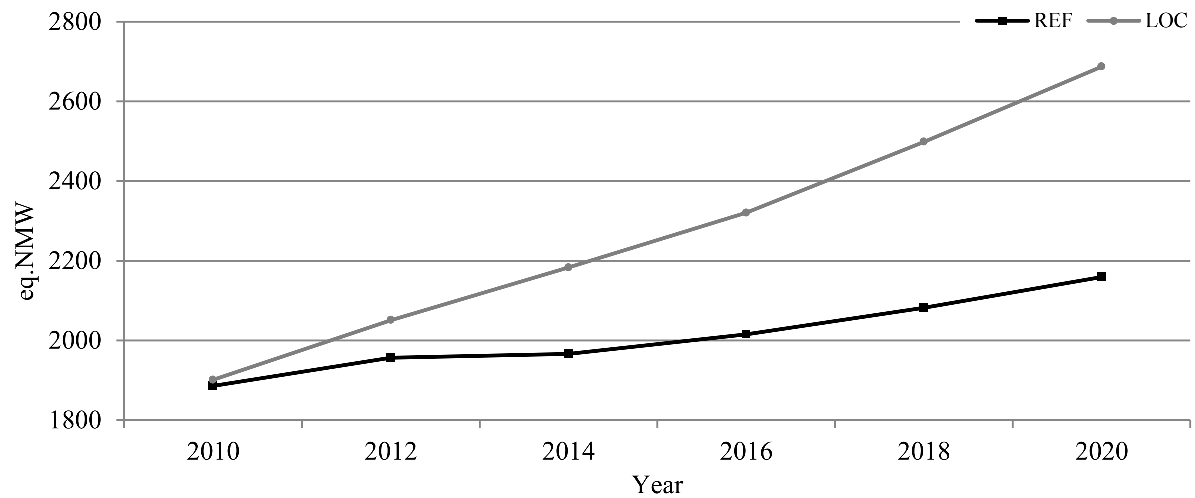


Figure 12: Evolution of total employment generated in Reunion and in France in the REF or LOC scenarios.

In Figure 13, the evolution of jobs created in Reunion is related to the evolution of the size of the population of Reunion. The slope of the curve is almost zero for the REF scenario because the evolution of jobs generated by the supply chain is aligned with local population growth.

The 70.4% increase in the volume of local production would generate (LOC scenario) 21% more NMW equivalent jobs per capita in the region by 2020 compared to the REF scenario.

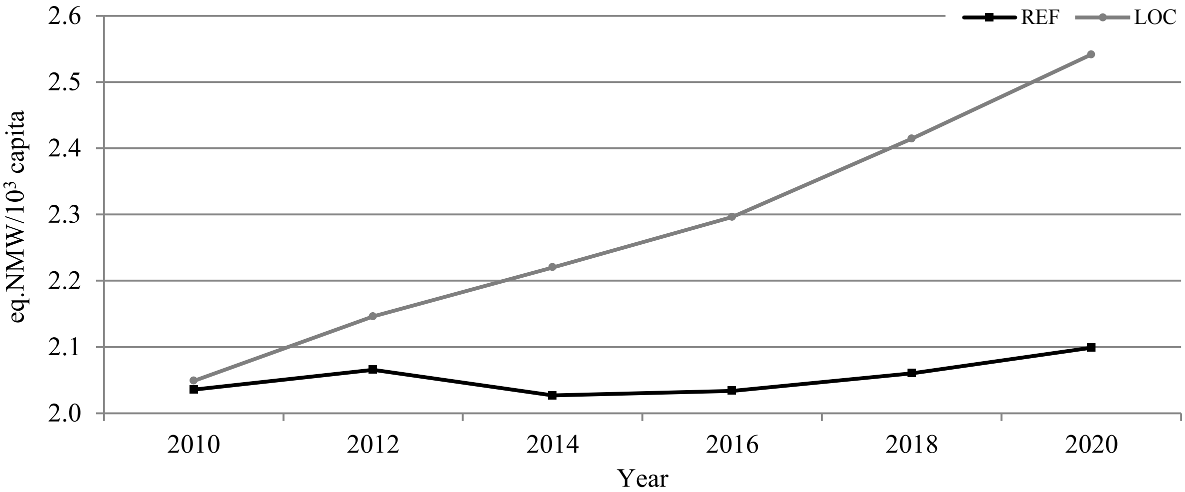


Figure 13: Evolution of total employment generated in Reunion for 1,000 people in Reunion in the REF or LOC scenario.

In Figure 14, the evolution of jobs created in Reunion is generated per ton of poultry meat supplied by the local supply chain and the import sector, and in Figure 15, per ton of poultry meat supplied only by the local supply chain. As food needs are correlated to changes in the population, we can see the same trend for Figure 14 as for Figure 13. Between the baseline year and 2020, total employment per 1,000 tons supplied in the region increased by 12% for the LOC scenario as against a 7% decrease for the REF scenario. In Figure 15, there is, however, a reversal of the curves relative to the previous three figures (Figure 12Figure 5,Figure 13, and Figure 14), with about 41 more jobs per 1,000 tons of poultry meat marketed for the REF scenario than the LOC scenario in 2020. This difference is explained by the decrease in direct recruitment observed in Figure 12 and the knock-on effects on the induced jobs associated with this (see Table 8).

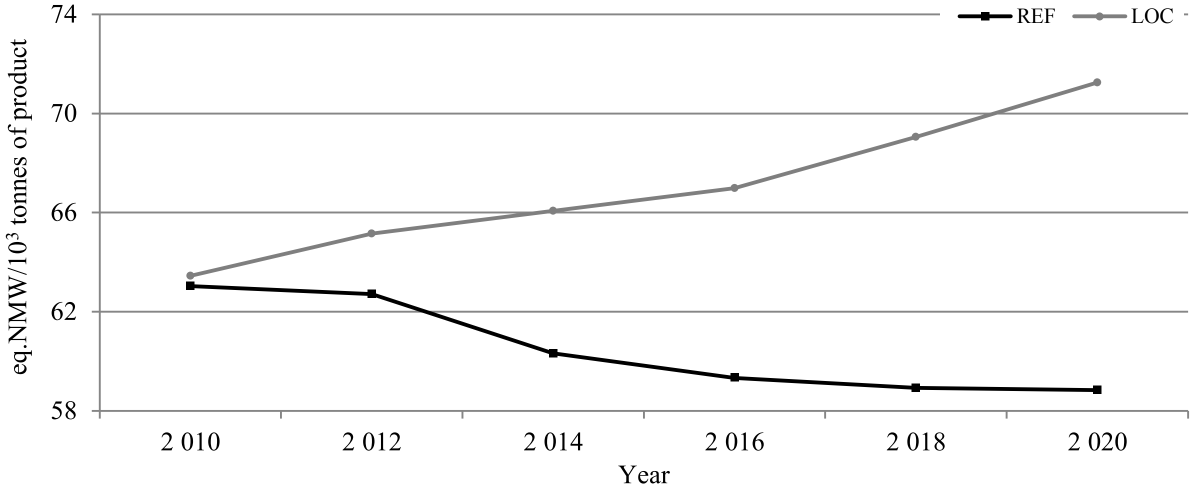


Figure 14: Evolution of total employment generated in Reunion per 1,000 tons of local and imported poultry meat supplied, in the REF or LOC scenario.

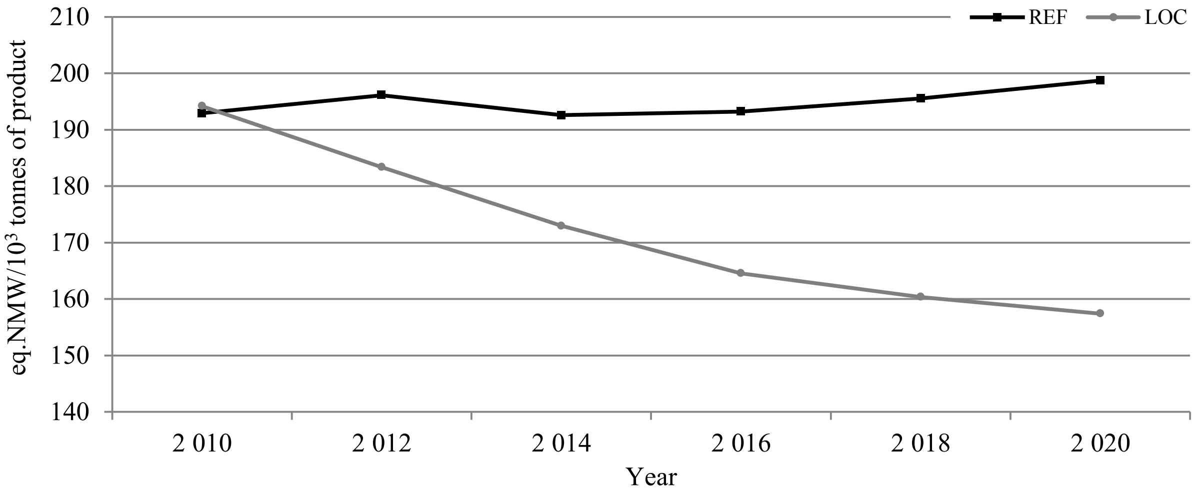


Figure 15: Evolution of total employment generated in Reunion per 100 tons of local poultry meat in the LOC or REF scenario.

4. Discussion

The methodology proposed in this article sets out to represent quantitatively the contribution to employment of the local agricultural sector, and also to characterise these jobs in terms of geographical location, socio-professional category and sector. We discuss the importance of these results in aiding local authority players in decision-making, but also in helping the agricultural sector to enhance their social image.

In our case study, significant distributional effects on Reunion and France were highlighted and show both a high degree of regional integration and a dependence on the continent. In 2010, a poultry farmer (i.e. 1.7 NMW equivalent jobs) from the supply chain enabled the upstream and downstream employment of 7.9 direct NMW equivalent jobs, 3.1 indirect NMW equivalent jobs and 4.3 induced NMW equivalent jobs in Reunion as well as 1.3

indirect NMW equivalent jobs and 0.7 induced NMW equivalent jobs in France. Most raw materials and intermediate goods, however, are not produced on the island. The breakdown by sector of jobs generated in Reunion (see Table 9) shows that the majority of these jobs are from the tertiary sector of the economy (> 60%). This sector represents 82% of the value-added created in the region in 2010 (as against 74% in France), while the secondary sector (excluding construction) represents only 5% of the value-added created (against 17% in France) (INSEE, 2010c, 2010a). The transport sector in the region exploits this recourse to imports in the sector with a 15% share of indirect jobs created. The geographical distribution of indirect jobs (see Table 7) confirms this, with 32% of indirect jobs in France of which 53% are in the sectors of supply of agricultural raw materials and intermediate goods (see Table 9). This situation is mainly due to the sector's recourse to an essential resource that is not produced on its region: cereals for animal feed. These results show that despite the absence of major crops, a large number of jobs related to support activities for production and businesses and local services depend on the sector's activity in the country. In addition, 20% of the direct jobs are located in rural areas. Using the multiplier of induced effects for Reunion (1.39), 253 direct and indirect NMW equivalents are involved in maintaining economic activity in those areas where unemployment is particularly high. These trends therefore provide local authority decision-makers with numerical arguments to justify the maintenance and promotion of local agricultural activities. This maintenance is also consistent with the current direction of the Common Agricultural Policy (CAP) aimed at developing rural areas by reconnecting producers and consumers. These guidelines are particularly directed towards short distribution chains that are integrated in the region, particularly through the support of farms that contribute significantly to employment (Kneafsey *et al.*, 2013).

The quantification of jobs for the two market share scenarios shows that for 53% growth in volumes produced locally, the local supply chain generates 20% more NMW equivalent jobs after 10 years (see Figure 12). Beyond the fact that the LOC scenario naturally enables the creation of more jobs than the REF scenario, in this scenario we observe a rate of job growth higher than the rate of demographic change (see Figure 13). Encouraging consumers to favour local supply chain (LOC scenario) at the expense of the import sector may seem anti-competitive if the strategic analysis of the region is not taken into account. In our case study, on the one hand, the Reunion region represents merely a clearance market for the import sector and therefore generates little value-added in the region and very little (transport sector) at national level. And on the other hand, the loss of business of some players in the supply chain could contribute to the desertification of rural areas. Coupled with the strategic analysis of local issues, this result highlights the challenge facing local authority decision-makers if the loss of competitiveness of the local poultry supply chain continues. In addition, for the State an unemployed person represents not only a burden on the welfare budget, but also a lack of tax revenue. The strategy of promoting local industries for food self-sufficiency planning can therefore, despite minimal losses on employment in France for the import sector, generate a double positive effect on the economic sustainability of the area: a step towards a balanced public expenditure and revenue budget and a boost for public primary and secondary sectors at national level. These are additional reasons which can be used by politicians to support agricultural production in Europe's outermost territories.

In areas facing serious obstacles in development, this type of result demonstrate the social importance of agricultural supply chain. Beyond a comparison of jobs in absolute terms, this significant growth in total employment can be per ton of products consumed in Reunion (see Figure 15), in the manner of the functional unit in an environmental life cycle assessment (Guinée *et al.*, 2002). These results highlight the impact of consumer choice on the social development of the surrounding environment, in this case Reunion. The switch toward 1,000 tons of local produce consumed (i.e. 28,000 consumers changed their consumption habits in favour of local products), would create 157 additional NMW equivalent jobs in the region. In future, social labelling of agricultural products, in the manner of environmental labelling based on the environmental life cycle assessment (Van der Werf *et al.*, 2010), would meet the new objectives of the CAP through a knock-on effect via the consumer. Opportunities for greater alignment between methods of economic evaluation and life cycle assessment have recently been demonstrated and are confirmed in this study (Earles and Halog, 2011). However, the realisation of this goal remains an important methodological challenge due to the complexity of the network of players in which an agricultural supply chain can be integrated (Boons *et al.*, 2012; Jarosz, 2000). The supply chain is a useful unit of analysis for defining effectively the system in which the environmental impacts of a product are evaluated. But in terms of the social aspect, identifying the scope of application of the calculated effects, defined in terms of the players actually affected by changes in production (Swarr, 2009), is not obvious and is one of the major difficulties of the method proposed here. For example, in this study, the intermediate consumption that changes due to the marginal change in production is taken into account in the calculation of employment generated but the consequences of variations of intermediate products such as poultry litter and other recoverable waste are not evaluated. These products are, however, likely to compete with other sectors. Similarly, the calculation of the effects on all suppliers is not relevant from a policy and operational perspective, for example for the implementation of improvement scenarios. The use of a cut-off criterion based on the revenue associated with the manually chain ascending procedure allowed us to minimise the uncertainty about the players potentially most affected by the decisions of the sector by maximising the precision required for these players (see section 2.3). This approach echoes those used in strategic management, such as the theory of resource dependence, in order to select the key stakeholders for the firm (Pfeffer and Salancik, 1978). Methodological developments are beginning to emerge in this sense which can be used to delineate the scope of the social impact assessment of supply chain within their network of stakeholders (Ayuso *et al.*, 2012; Loorbach and Wijsman, 2013; Porter and Derry, 2012). This type of approach could enable account to be taken in future of the impacts on players connected to the core of the supply chain by economic flows (suppliers) as well as the side effects which can be significant for the players not linked by economic flows (competitors, the community) (Lagarde and Macombe, 2013). For direct competitors, this was not the case for the baseline year in the study presented here because these potential competitors marketed their products in different markets to the local supply chain. In situations where these collateral effects are important, they must absolutely be taken into account in order that progress towards sustainability of the supply chain may be measured.

5. Conclusion

In this article, we evaluate the contribution of an agricultural supply chain to the social development of its region by the quantification of the jobs generated by its activity. These jobs were characterised by geographic area, sector and socio-professional category. At the baseline in 2010, a poultry farmer (i.e. 1.7 NMW equivalent jobs) working in the supply chain enabled the deployment upstream and downstream of 7.9 direct NMW equivalent jobs, 3.1 indirect NMW equivalent jobs and 4.3 induced NMW equivalent jobs in Reunion and 1.3 indirect NMW equivalent jobs and 0.7 induced NMW equivalent jobs in France. These figures and associated additional results reflect the strong territorial integration of the activity of the sector but also a dependence on the continent for raw materials. Two scenarios outlining changes in market share distribution between the local supply chain and the import sector were compared. When the local sector wins newly available market share, it demonstrates an employment rate higher than demographic growth in the area.

Greater alignment between project evaluation methods, life cycle assessment methods and strategic business management are possible and useful measures in defining more precisely the scope of analysis of the system and enabling the more accurate assessment of these effects. Following this study and from the perspective of support for decision-making, the use of this methodological approximation appears to us a key way forward towards building a common sustainability assessment framework for assessing the consequences of decisions at supply chain level in social, environmental and economic terms.

Acknowledgments

This work was funded by *Crête d'Or Enterprise* and CIRAD. We are grateful to all the firms and farmers who contributed to inventory.

Chapitre 3 – Chapitre 4

Dans le chapitre 3, nous avons dérivé l'objectif initial de la méthode des effets, « réaliser l'analyse coût-bénéfice d'un projet », pour ne caractériser que les effets de l'activité d'une filière sur son environnement industriel et sur la communauté qui gravite autour. Ces deux catégories d'acteurs sont cruciales pour la durabilité économique et sociale du territoire. L'environnement industriel de la filière correspond en effet à un réseau de fournisseurs qui participent à la santé économique et à l'attractivité du territoire en matière d'investissement. De plus, dans le cas de l'évaluation d'une filière agricole, une partie potentiellement importante de la communauté associée se situe en zone rurale[1], ce qui contribue à limiter l'exode rural et participe donc à une répartition plus homogène des populations sur le territoire. Cependant, les effets calculés sont loin d'être exhaustifs pour évaluer la durabilité sociale d'une activité de production. Nous avons fait le choix de limiter l'évaluation au calcul des emplois créés, mais d'autres méthodes, encore en développement, permettent d'aller plus loin. Ces méthodes peuvent se diviser en deux approches: les méthodes d'évaluation de la performance sociale des entreprises ou *ACV des performances,* et les méthodes permettant d'évaluer les relations de type cause à effet ou *ACV des pathway* (Feschet, 2014). Les premières permettent d'évaluer des performances sociales traduites par des indicateurs en lien avec le champ de la responsabilité sociale des entreprises (RSE; p. ex. le travail des enfants ou le nombre d'accidents du travail) (UNEP/SETAC, 2009). Les deuxièmes traduisent des relations de type cause à effet et permettent d'évaluer des impacts et non des performances. Par exemple, de récents développements utilisant la relation de Preston permettent de lier les revenus dégagés par l'activité d'une entreprise ou d'une filière à la santé des populations (Feschet *et al.*, 2013). Le champ de recherche de l'ACV sociale est cependant relativement récent comparé à

[1] Les emplois induits définis comme « la communauté » correspondent aux salaires générés par les dépenses des employés de la filière à proximité de leur lieu de vie et donc en grande partie en zone rurale.

l'ACV environnementale et requiert des travaux dédiés pour étendre et approfondir le panel d'indicateurs à évaluer.

Le chapitre 3 a permis d'identifier certaines contraintes de cette méthode par rapport à la finalité de cadre conceptuel, notamment le problème de la prise en compte de la totalité des parties prenantes dans l'évaluation. En effet, la finalité du cadre conceptuel décrit en chapitre 1 est son opérationnalisation. Il se traduit dans notre cas par le développement d'un outil permettant d'identifier où et chez qui des actions d'amélioration de la performance doivent être entreprises prioritairement. Le nombre de collaborateurs, fournisseurs, et compétiteurs pour l'ensemble d'une filière pouvant être important, il est nécessaire d'effectuer une sélection pour ne garder que ceux essentiels à l'étape aval de l'évaluation, la mise en place des actions. Par exemple, les prises de décision de la filière n'ont aucun effet sur des grands groupes internationaux comme le fournisseur de soja argentin. De plus, la filière n'a aucune influence sur ces mêmes groupes pour les inciter à améliorer la durabilité de leurs pratiques. Ces groupes peuvent donc être éliminés de l'évaluation s'ils ne sont pertinents ni en termes d'effets ni en termes d'aide à la décision. L'utilisation de critères de coupures fonctionnant sur un principe similaire à ceux utilisés en ACV environnementale constitue un des points d'articulation des deux méthodes dans le cadre conceptuel proposé.

La méthode proposée est particulièrement compatible vis-à-vis des critères énoncés précédemment. La méthode des effets ayant été développée pour évaluer des filières dans les pays en voie de développement (Chervel *et al.*, 1997), les différentes techniques employées (p. ex. remontée de chaîne, consolidation des comptes) permettent une bonne adéquation avec la méthodologie d'élaboration du système explicitée dans la construction du cadre conceptuel dans le chapitre 1. De même, il est possible, soit dans l'étude des comptes de production-exploitation, soit par la décomposition de la matrice Input-Output régionale, de spatialiser la redistribution de la valeur ajoutée. Ces étapes permettent en quantifier la richesse créée ou détruite par l'activité de la filière sur et en dehors du territoire, et donc de caractériser les effets sur l'environnement industriel et les communautés associées de façon géographique. Enfin, la méthodologie pour construire le compte consolidé peut être couplée avec de la méthode d'inventaire de l'ACV (cf. chapitre 2) afin d'aboutir à une base de données unique permettant de dériver l'ensemble des indicateurs. Plusieurs degrés de précision devront être définis, car comme en ACV, il est difficile de mener un inventaire exhaustif du berceau à la tombe sur l'ensemble des intrants de la filière. Dans le chapitre 1, une méthodologie basée sur l'analyse de l'environnement stratégique de la filière et permettant de délimiter ces degrés de précision est détaillée.

Dans les chapitres 2 et 3, nous avons montré la compatibilité des méthodes sélectionnées avec les principales lignes du cadre conceptuel. Certaines adaptations, comme la redéfinition des limites du système, seront nécessaires afin de les intégrer correctement. Le chapitre 4 présente l'application du cadre conceptuel et des méthodes sélectionnées sur la filière avicole réunionnaise.

Chapitre 4

Food chain sustainability assessment, Part II: the case study of poultry meat supply of a tropical island

Submitted *in Journal of Cleaner Production*

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Abstract

Food chains can be powerful driving forces for sustainable development. In this paper, a new framework for sustainable assessment is applied to analyse the contribution of the main poultry supply chain in Reunion Island to the sustainable development of this island territory. Sustainability was assessed over a three-year period using a transdisciplinary approach paying particular attention on the involvement of the main stakeholders of the supply chain. The stakeholders participated in framing the problem, selecting the appropriate indicators, and interpreting the results. The first system delimitation included all stakeholders whereas only the salient stakeholders were selected for the assessment. Two assessment methods were used depending on the indicators chosen in collaboration with the stakeholders: environmental life cycle assessment and input-output analysis. Indicators were spatialized and grouped in six categories to represent what parts of the social-ecological system needs to be in Reunion Island. Our results revealed a highly complex network of firms involved in the supply chain. We show how the proposed framework can simplify interpretation for decision makers by focusing only on the most salient firms. Among the 1,126 firms involved in the supply chain, efforts were thus concentrated on 139 firms which are salient for the social subsystem and 124 which are salient for the ecological subsystem. Spatial differentiation of effects is a useful way to underline the transfer of impacts between territories. For the ecological subsystem in Reunion Island, the effects linked to supply chain activities which threaten resources conservation and ecosystem health are mostly externalized due to the strong dependency on foreign resources: fossil energy and raw materials used for livestock feed (e.g. 97.5% of impacts on freshwater ecotoxicity occur outside the territory). On the island, most damage occurs is to the ecosystem and human health. Concerning the social subsystem, the supply chain provides employment on the island due to the use of local services (e.g. 89.7% of indirect jobs are provided on the territory). Several environmental mitigation measures were integrated and tested through scenarios. Improvement of on-farm eco-efficiency was shown to be a mitigation measure that significantly affects the food chain.

Human and ecosystem health and resources conservation would be improved by this measure (+14%). But the community and the supply chain industrial network would also be negatively affected (-2.5%). Multi-criteria analysis is particularly useful for decision making. It makes it possible to evaluate the necessary trade-offs between resources conservation, ecosystem and human health on the one hand, and employment in the supply chain industrial network and the surrounding community on the other. This type of analysis involves a heavy burden of data collection and analysis. The firms' participation guaranteed complete high quality data. Data availability is probably the most important limitation for a broader implementation of the proposed framework to assess other food systems around the world.

Keyword: Sustainable development, life cycle assessment, input-output analysis, broiler supply chain, Reunion Island

1. Introduction

There is an urgent need for progress towards more sustainable agriculture. Agriculture currently has major impacts on ecosystems (soil and water pollution, loss of biodiversity), climate (greenhouse gas emissions), resources depletion (fossil resources), human health (contaminated water and air), and community livelihoods (rural exodus). The agricultural practices responsible for those impacts are well known but a more comprehensive view of how agriculture is embedded in nature and in social dynamics is required to enable a real move forward (Waltner-Toews and Lang, 2000). The main food system encountered with respect to productivity is the agro-industrial system (J.L. Rastoin and G. Ghersi, 2010). This system tends to spatially separate customers and processes whereas historically, communities have been established around agriculture activities (Tansey and Worsley, 1995). Today the cumulative distance of a product between the different steps in the chain from production to delivery to the consumer can be trans-national or trans-continental. As a result, the people who benefit from the first function provided by agriculture, food security, are no longer connected with people who benefit from the second function, income. While this situation is encountered in many other industrial sectors (e.g. mining), the agricultural industry is more serious because, more than any other industrial sector, it fulfils both basic functions and because the production stage and its feedback mechanisms are closely interrelated with nature. Relationships between actors of the food chain have progressively lost a sense of responsibility toward humans and nature they previously embodied and have become mere economic exchanges. Polluters are both far from and close to their customers. Far from, because the focal firm which carries most of the responsibility for - and the notoriety of - the supply chain (Kovacs, 2008) is detached from the source of pollution; and close, because the supply chain activities with the most impact affect its direct community. However, in the last few years, a change has been observed in customer awareness that takes the form of a preference for shorter food chains, i.e. within a territory (Watts *et al.*, 2005). This shift is reflected in the increasing number of direct sales channels, community-supported agricultural organisations, and the development of local and national labels (Barham, 2003). These organisational models generally symbolise values like food safety, quality, traceability and low environmental impact (Renting *et al.*, 2003). This growing movement is now supported by high instances including the European Union, which promotes short integrated supply chains through its common agricultural policy (Kneafsey *et al.*, 2013). The paradox of 'modernity in agriculture' might be the return to past organisational patterns. However, to date, such organisational models have a low market share and are far from supplying entire communities or cities (Friedmann and McNair, 2008). A compromise could be reached between the agro-industrial system practices and initiatives in the sense of short integrated supply chains. But, like any other business model undergoing change, it faces two problems: stakeholders' empowerment and commitment, and the need for rational arguments to monitor progress and build support. The stakeholder network in which food chains are embedded can be very dense and complex. New frameworks are thus needed to describe the complexity and to help managers of firms and policy makers to inform their decision making (Govindan, 2013).

In a companion paper, we described the theoretical background of a new framework created specifically to assess progress by the food chain toward sustainability (Thévenot and Vayssières, 2013). Both neoclassical economics and eco-efficiency approaches currently used in the strategic management field fail to provide a relevant framework for the assessment of sustainability because they are corporate-centred and do not account for externalities. The proposed framework is based on three critical points. 1) First, even for industrial activities, the framework encourages a search for sustainable strategies through a transdisciplinary approach to enable the most exhaustive problem framing in which their activities are embedded; 2) The framework recommends a clear definition of the spatial scale of the analysis so as to be able to evaluate the main principle of sustainable development: equity between territories, and the main precondition for success: efficacy; 3) The framework suggests reviewing the way to deal with stakeholders. The construction of the framework was based on several recent developments in stakeholder theory, which suggest initially including a wider range of stakeholders than in the social-ecological system in which the food chain is embedded, and then selecting only the salient ones.

This second paper describes a case study in which the framework was applied: the assessment of different development scenarios of the poultry chain supplying meat to inhabitants of Reunion Island, a tropical island in the Indian Ocean. Given the increasing concerns of the local population about environmental and social issues, mitigation measures are included in the development scenarios. The aims of this paper are to i) evaluate the ability of the framework to provide useful indicators for decision making, ii) identify methodological perspectives to expand the scope of the application of the proposed framework.

2. Materiel and methods

2.1. The case study

The subject of the case study is the main local poultry supply chain in Reunion Island. This poultry supply chain is well organized thanks to a clear division of tasks and to the support of an inter-professional association, which ensures cohesion between firms. A survey in 2007 showed that two animal feed factories imported and processed feed concentrates for all types of livestock on the island. Another firm supplied all broiler farms with one day old chicks. This firm comprises three hatch egg producers, two hatcheries, and two rearing units, It imports breeders from mainland France at one day old and these are reared to provide the one day old chicks for the broiler farms. About 120 broiler farms provide 13,000 tons of live weight broilers to two slaughterhouses. One slaughterhouse is sized to slaughter 23,000 broilers (the main species) per day and the other 3,000 complementary species per day. This food chain functions on demand. The key decisional entity is therefore the focal firm which markets the final product (L. Ploquin, 2011). The supply chain has relationships with suppliers in Reunion Island, in mainland France, and in countries all over the world. It has competitors both on the island and in mainland France.

2.2. A transdisciplinary approach

This case study was carried out over three years on the initiative of the focal firm of the main local poultry supply chain in Reunion Island. An iterative participatory process was set up through meetings to frame the problem. The first iteration included researchers and managers of the focal firm. The second iteration included the same people plus collaborators of the focal firm along with representatives of several institutions involved in local agricultural governance. The third iteration involved salient stakeholders and salient competitors of the supply chain. Salient actors who were not able to attend the meetings were contacted by email or by phone to keep them informed about the main conclusions of the meetings and to get their opinion. Between each iteration, the problem, indicators, methods, and tools were fine tooled ready for presentation at the following meeting. The problem framing step was carried out using both a top down approach, i.e., proceeding from the characteristics of the territory to the stakes, and a bottom up approach, i.e., from the stakeholders to the stakes (Ravetz, 1999).

3. Problem framing

3.1. Strategic analysis of the territory

Strategic analysis of a territory requires a spatial approach to describe it in three dimensions: identitarian, material, and organisational. The goal of this distinction is to better operationalize the problem framing.

Identitarian dimension

Reunion Island is a tropical island in the Indian Ocean near Madagascar (21° 09′ S 55° 30′ E). The island covers 2 512 km² and the population in 2012 was 840,000. Due to the more clement climate on the north, south and west coasts, most of the population is gathered in the main towns. The population comprises descendants of immigrants from Madagascar, Africa, India, and China and of people from mainland France. In 1946, the island status was changed from French colony to French department and its population from mostly slaves to French citizens who are now European citizens (Médéa, 2003). Because of the need for sugar in mainland France, the economy of the island was for many years mainly based on income from sugar cane, which, in the early 1970s, still represented 25% of the regional *gross domestic product* (GDP) (Widmer, 2005). Over the next 40 years, economy underwent a major shift, with tertiary activities representing 85% of the GDP and the income from sugar cane representing less than 1% in 2011. Reunion Island thus has a radically different history than other French regions.

Material dimension

Reunion Island is a volcanic island with basaltic soil, high elevation (0 – 3,070 m asl.) and a hilly relief with steep slopes. The climate is tropical with hot humid summers and warm winters; the island is located in a high-risk area for cyclones. A few non-renewable resources are available (e.g. sand) but most essential resources are not (e.g. fossil and mineral resources). Renewable resources including forest exist but contain significant internationally recognized biodiversity, which limits their exploitation (UNESCO, 2013). Groundwater is also a sensitive resource, which is limited and sensitive to pollution because of the porous nature of the basaltic soil (Join *et al.*, 1997). A coral barrier reef borders 20 km of the west coast which also hosts great biodiversity.

Organizational dimension

Reunion Island is a French department with the same laws and institutions as those in mainland France. Whereas it shares the same characteristics as its trade partners in the Indian

Ocean, Reunion Island presents a high deficit in its trade balance with a coverage rate (ratio of exports divided by imports) of about 6%. Economic subsidies encourage exchanges with Europe. The local livestock production sector supplies about 50% of domestic demand, the rest is imported mostly from Europe.

The choice of applying our framework in Reunion Island is justified by the fact that (i) the study area is isolated and, like most islands whose population density is high, food self-sufficiency is a major problem, (ii) the three territorial dimensions are easy to delineate in a small and very well delimited territory, (iii) the distinction between local and global is clear thus facilitating data collection.

3.2. Definition of the stakeholders and their interactions

The second step of the problem framing was a bottom up approach to define the perimeters of the social and the ecological subsystems in which the supply chain activities occur. The definition of this perimeter required screening the different types of stakeholder who interact within these subsystems. Criteria based on the distribution of value-added along the supply chain were first used to identify the social subsystem in order to delineate the salient stakeholders. For the ecological subsystem, criteria based on the consumption and emission of elementary flows were used with reference to environmental life cycle assessment methodology.

3.2.1. Stakeholders of the social subsystem

Suppliers

Suppliers were identified by moving upstream in the supply chain starting from the focal firm which markets poultry products using several retail channels. The discriminatory criterion was the economic dependency rate of each supplier to its customer. This rate is the total customer's supply costs spent on the supplier divided by the supplier's turnover. The economic dependency rate of each supplier was calculated iteratively at each step while moving upstream in the supply chain. This step was processed iteratively because a supplier could supply more than one firm in the supply chain (e.g. a firm which produced feed supplied both broiler farms and breeders). In this way, several thresholds based on the degree of coordination between the supplier and the supply chain, and the substitutability of the supplier were determined and allowed us to classify suppliers in two categories: i) salient stakeholders including collaborators and salient suppliers, and ii) non-salient stakeholders corresponding to more marginal suppliers. Each time a supplier was identified as a collaborator, their production account was investigated. Salient suppliers and collaborators were grouped under a single indicator named ‘supply chain industrial network’ (SCIN).

Community

In Reunion Island, communities are highly concentrated near industrial or commercial zones mostly due to the narrowness of the territory and because of the serious delays in the construction of roads and public transport with respect to population growth. Around 53% of the population live and work in the same town compared with 24% in mainland France (INSEE, 2010e). Thus social cohesion is indispensable for an industry’s longevity, and loss of value in the system that might affect communities need to be identified. The poultry chain’s employees, the supplier’s employees, and any competitor’s employees create value in the very next community which might be affected by the firm manager’s decisions. Community is defined here as a ‘salient stakeholder’ and grouped under an indicator named ‘Community’.

Competitors

Salient competitors were identified using game theory principles (Grandval and Hikmi, 2005). The result of this analysis is highly subjective because of the difficulty in correctly defining who and to what degree actors are in competition. In our case, from a customer’s point of view, the function the poultry supply chain fulfils can be either supplying them with chicken meat, or with animal protein, or even simply protein. Depending on how this function is defined, competitors of the supply chain could be either other poultry supply chains, or pork or cattle producers, or soya producers. In this study, the range of competitors was limited to other actors who supplied the same market with poultry meat as the main supply chain. Several competitors were identified, investigated, and classified in two types: salient competitors and marginal competitors, according to three criteria: volumes supplied and global market share, market share in each retail channel, and capacity to expand in each retail channel in the next ten years. Competitors were defined as ‘salient stakeholder’ and grouped under an indicator named ‘Competitors’.

3.2.2. Stakeholders of the ecological subsystem

Human stakeholders

As living beings, humans can be considered as stakeholders of the ecological subsystem. Most pollutants emitted into the air have an impact on human health at local scale in the form of toxicity for humans, formation of photochemical oxidants, formation of particulate matter, and ionising radiation. Pollutants emitted into freshwater can cross territories, but in Reunion

Island this is not the case, consequently emissions into the air and into water were considered to directly affect people on the island. Ozone depletion is the only one that has impact at global scale. Several different methods of characterisation can be used to model the large number of carcinogenic and non-carcinogenic substances.

Non-human stakeholders

Impacts on the environment are defined as consumption of non-renewable resources (depletion of fossil fuels, depletion of metals) and emissions that affect ecosystem health (climate change, soil acidification, eutrophication of freshwater, terrestrial ecotoxicity, freshwater ecotoxicity, and marine ecotoxicity). Several methods can be used to characterise the impact on the ecosystem of substances consumed or emitted, and their effect can be aggregated in a single unit for each impact category.

3.3. Calculation methods and tools

3.3.1. Social subsystem

Employment generated by supply chain activities was handled at two scales: global and territorial, and in three categories: direct employment for collaborators, indirect employment for salient suppliers and competitors, and induced employment for communities. Direct employment was calculated using the expenditure account of collaborators. Indirect and induced employment for salient suppliers, community and competitors were calculated using input-output analysis (See (Thévenot *et al.*, 2013c)). The degree of accuracy and reliability diminishes from territorial to global and from direct to induced employment. Job units are expressed as national minimum age equivalents, which correspond to the annual minimum gross salary an employer is legally bound to pay to its employees. In France in 2007, the national minimum wage was €15,206/year.

3.3.2. Ecological subsystem

For collaborators, full account assessment of consumed and emitted substances was performed. For salient suppliers, environmental life cycle assessment methodology was used. All impacts were calculated using Simapro v 7.3.3 software (PRé Consultants, 2008). All calculations and hypotheses (system boundaries, allocation method, etc.) are described in detail in (Thévenot *et al.*, 2013a).

The ReCiPe Midpoint and Endpoint method were used to characterise substances for each impact category and then to normalize the impact categories into three single categories: resources conservation, ecosystem health, and human health (Goedkoop *et al.*, 2009). The normalization procedure makes it possible to transform the results of each impact category into a relative contribution of the product to a reference situation (Sleeswijk *et al.*, 2008). All impacts are therefore expressed in the same unit of measure to make it easier to compare impact categories (Norris, 2001). The global or the national economic system are usually used as reference situation because they offer a global coverage of life cycle processes (Guinée *et al.*, 2002). Since the consumption patterns in Reunion Island are similar to those in Europe, we used the weighting set "Europe ReCiPe H/H" from the ReCiPe method (Sleeswijk *et al.*, 2008).

3.4. Definition of scenarios

Two types of scenarios were built. The first type was a prospective scenario to simulate changes in volumes produced by the supply chain over time. It provided a dynamic view of the system (number and size of firms and of flows between these firms). Here, the time horizon used for the analysis was ten years. The underlying assumptions were expected population growth over ten years and the corresponding increase in the demand for poultry meat. Poultry meat consumption has stabilized over the past five years, and so we assumed that consumption patterns would not change over this time horizon. This projection also included different hypotheses concerning changes in market shares among competitors. The second type of scenario was a set of mitigation measures implemented over the same time horizon. The purpose was to evaluate their effectiveness for progress toward sustainability and to identify possible trade-offs in the case of need. The scenarios were consequently implemented individually and in combination. These measures included equipment upgrading, improvement in farm eco-efficiency and limitations represented by transport.

Equipment upgrading referred to (i) setting up a biogas plant to digest slaughter wastes which were previously burned in an incinerator on Reunion Island; (ii) installing photovoltaic solar panels on the roof of the slaughterhouse.

Farm eco-efficiency referred to improvement in the feed consumption efficiency of broiler farms. The feed consumption rate of inefficient broiler farms was reduced to the same level as that of the best farms today.

Transport limitation referred to the shift in the country from which maize is imported. Maize represents more than 50% of broilers' diet and is currently imported from Europe, i.e. over a distance of 10,000 km, whereas closer countries in the Indian Ocean could supply Reunion

Island. In this scenario, maize is imported from Mozambique instead of Europe. It is assumed that both economic and political barriers have been overcome.

3.5. Data collection

The model upon this framework was built used Microsoft Office Excel software. In the first spreadsheet, a common inventory of economic and elementary flows was performed based on the consolidation of production-exploitation accounts of all the collaborators of the supply chain. The resulting account was then combined with material flow accounting and air pollutant emission reports. Economic and elementary flows were spatially differentiated in the inventory by adding a location criterion. The second spreadsheet was linked with the first one; it was the user interface and contained a form allowing optional mitigation and growth scenarios to be configured. The Excel workbook was connected with a Microsoft Office Access database that contained characterisation factors extracted from the EcoInvent database and the spreadsheet of embedded rates deduced from the regional input-output table.

3.5.1. Collaborators

The revenue and expenditure account and the social report of each firm classified as a collaborator were used to calculate direct employment. For raw materials and emissions, data were collected during surveys or from the literature. All hypotheses and data sources are listed in a previous publication (Thévenot *et al.*, 2013a).

3.5.2. Suppliers

The annual national accounts for France and Reunion Island were used. These data are provided by the French national institute of statistics and economic studies (INSEE, 2010c, 2010a). The accounts are based on Leontief Input-Output analysis (Leontief, 1936). The input-output table for each account (Reunion Island and France) was modified in a new table from which the increase in local value and the intermediate imports for each activity sector can be deduced when there is an increase in final demand (see Chervel *et al.* (1997) and Thévenot *et al.* (2013c)). For raw materials and emissions, the EcoInvent database (Frischknecht *et al.*, 2005) or inventories available in the literature were used.

3.5.3. Community

The statistics on household consumption (INSEE, 2007, 2010b) were broken down into the respective modified input-output tables mentioned in the previous paragraph (see §3.5.2) in order to calculate the effect on induced employment generated by the expenditure of the wages of collaborators and of suppliers' employees.

3.5.4. Competitors

The poultry meat market was sized using top down (evaluation based on the needs of the population) and bottom up approaches (evaluation based on competitor's production estimations). There are only two feed factories and two chick producers on Reunion Island so we were able to accurately estimate the volumes supplied by cross-checking data with the main poultry supply chain performances. An approximation of the turnover of the salient competitors and their market share was calculated using the estimation of volumes supplied and market price. The estimated employment that could be destroyed, the market share equivalent to volumes in competition with the supply chain under study were broken down into the respective modified input-output tables mentioned in §3.5.2.

3.6. Scenarios

Mitigation scenarios were based on on-going projects. Data were therefore collected in the forecast reports from consultancy agencies. For the biogas scenario, biogas and heat generated are destined to be used as a substitute for fuel in the currently oil-fired boiler system of the slaughterhouse and were consequently converted into fuel equivalents based on their respective lowest heating value. However the equipment that enables the plant to function would increase total electricity consumption. The solid output of the digester was assumed to be used as fertiliser for sugar cane. The environmental impacts of the corresponding amount of mineral fertiliser avoided were credited back to the system (Audsley *et al.*, 1997). The liquid part was treated in the communal waste water treatment plant. For the solar panel scenario, the amount of electricity produced by the panel was deduced from the total amount of electricity consumed. The environmental amortization of the solar panel was taken into account. For the farm eco-efficiency scenario, the feed consumption rate of inefficient broiler farms was reduced to the score of the best farms in the sample. The corresponding amount of ammonia gaseous emissions was also reduced. The best farms consume more electricity because they use ventilation equipment. So electricity consumption by inefficient farms was increased to that level. For the scenario in which maize is imported from Mozambique instead of Europe, the transport distance from Beira port (Mozambique) to the port in Reunion Island was evaluated and technical operations in Mozambique were assessed using local average data for a large maize production area with high expansion potential (IIAM, 2011). Direct emissions from maize fields were estimated according to (Nemecek and Kägi, 2007).

4. Results

4.1. Identified stakes

To identify the stakes in Reunion Island where the supply chain has leverage and where improvements are required, the results of the strategic analysis of the territory were combined with the results of the stakeholder analysis.

Identitarian dimension: In Reunion Island, its long-term status as a colony slowed down the effect of compulsory schooling. Moreover, the transition of the economy from the primary to tertiary sector was delayed compared with the same transition in Europe but, when it happened, it happened really fast. This transition was not predicted by government institutions and was accompanied by other social phenomena including the entry of women into the job market (Temporal, 2006). Together, these situations resulted in a high unemployment rate that has been worsened by the global crisis and reached 29.5% in 2011. This high unemployment rate can be linked with many social problems (precarious conditions, health problems, and inequalities) that threaten the stability and the social cohesion of communities (Thévenot *et al.*, 2013c). In terms of the development of the supply chain and of the territory as a whole, this situation implies a difficult compromise between reducing the cost of wages and supporting employment. Losses in the total value added distributed among collaborators, suppliers and competitors can seriously affect the community through the induction effect on employment. We thus considered the ‘creation and destruction of jobs’ to be a key stake in the social subsystem in Reunion Island.

Material dimension: The narrowness of the territory and the absence and/or the vulnerability of renewable and non-renewable resources have led to substantial reliance on maritime imports to meet the demand for raw materials to feed livestock as well as most material inputs for all kinds of suppliers. Maritime transport over long distances increases economic costs; its main impacts are on marine ecotoxicity, fossil fuel depletion and climate change. The narrowness of the territory and its isolation from mainland France also implies that electricity is generated by a local electricity mix mostly based on fuel and coal power plants. These types of power plants release pollutants and particulate matter into the air and water and have impacts on human and ecosystem health. In addition, the narrowness of the territory increases the proximity of people to these types of power plants. This situation thus increases community exposure to atmospheric pollution and increases the risk of impact on human health.

The hilly relief and steep slopes imply trade-offs particularly in road transport to supply farms with inputs (e.g. feed concentrates). Because of the characteristics of the relief, big roads cannot be built, meaning only small trucks can be used. Steep relief and low transport efficiency imply higher fuel consumption and higher emission of atmospheric pollutants. The hilly relief also implies to trade-offs in infrastructure because large facilities cannot be built to enable economies of scale. Finally small trucks and small roads increase not only the necessary labour force but also environmental impacts and economic costs. In Reunion Island, basaltic soils, limited and vulnerable water resources, and the vulnerable reef barriers require extra care to avoid the release of pollutants into water and air. Several activities e.g. transport by trucks, incineration and electricity production, generate just this type of pollution.

Organisational dimension: The European Union has arrangements (mitigation of the additional costs for the supply of essential products) for its outermost regions through a special programme (POSEI) included in its common agricultural policy. However Europe also allows an export subsidy (export refunds) that helps mainland poultry supply chains to export their co-products to Reunion Island at a price that outcompetes local production and seriously affects the economic performance of the local supply chain.

4.2. Selected indicators

Results of the strategic analysis of the territory, identification of common stakes, the stakeholders affected, and the corresponding indicators are summarized in Table 11. Employment was selected as the main indicator to assess the effect of the supply chain on suppliers, competitors, and on the community. The formation of particulate matter at the scale of the island territory and human toxicity at global scale were selected as impact categories to represent effects on human health. Soil acidification was selected to represent the effect on ecosystem health at the scale of the island territory. At global scale, fossil fuel depletion was selected for resources conservation, and freshwater ecotoxicity, freshwater eutrophication, marine ecotoxicity, marine eutrophication and terrestrial ecotoxicity were selected to represent effects on ecosystem health.

Table 11: Connection between territorial (Reunion Island) and global stakes and impacts of the activities of the supply chain

Main characteristics of the island territory	Consequences for supply chain functioning	Scale of impacts	Affected stakeholders	Indicators
Narrow territory with limited agricultural area and high population density	Import dependency, maritime transport	Global	Ocean	Marine eutrophication
		Global	Ocean	Marine ecotoxicity
	Import dependency, employment abroad	Territory	Community	Decrease in job creation/
	Proximity of industry & the community	Territory	Human	Formation of particulate matter
Mountainous relief	Small trucks for delivery of inputs and collection of poultry products (higher particle emissions and consumption rate)	Territory	Human	Formation of particulate matter
		Territory	Human	Formation of photochemical oxidants
		Global	Fossil resources	Fossil fuel depletion
	Coal - Fuel electricity based	Territory	Soil	Soil acidification
		Territory	Human	Formation of particulate matter
		Territory	Human	Human toxicity
		Global	Fossil resources	Fossil fuel depletion
Tropical climate (with high temperatures)	High ventilation rate in farms	Territory	Soil	Soil acidification
		Territory	Human	Formation of particulate matter
		Territory	Reef barriers - Lagoon	Marine eutrophication
		Territory	Ocean	Marine ecotoxicity
Transition from agriculture to tertiary sector	Unemployment	Territory	Community	Decrease in job creation/

4.3. The salient system

4.3.1. Suppliers

In Table 12, the distribution of suppliers is presented according to their economic dependency on the customers to whom they are connected. Moving upstream in the supply chain, 1,041 suppliers were involved in economic flows with the supply chain. The economic dependency rate of 125 suppliers was greater than 70% and they were thus classified as collaborators. Fourteen suppliers had an economic dependency rate of between 5% and 70% and were classified as salient suppliers, and 902 suppliers had an economic dependency rate of less than 5% and were classified as non-salient suppliers and eliminated from the previously defined industrial network of the supply chain. Collaborators classically include actors involved in the final transit of the product or the feed factory, the chick breeder, broiler farm cooperative, broiler farms, the slaughterhouse where the product is processed in Reunion Island: and the marketing division. Salient suppliers include the strategic actors of the supply chain, the most important of whom were road haulier, incinerator plant, packaging distributors.

Table 12: Distribution of suppliers according to their economic dependency rate on the poultry supply chain

% supplier turnover	[0 ; 5[	[5 ; 70[	[70 ; 100[	Total
Number of suppliers	902	14	125	1041
Share	86.6%	1.3%	12.0%	100.0%

4.3.2. Competitors

Competition on the poultry meat market in Reunion Island is described in Table 13. The survey showed that three types of poultry meat suppliers exist in Reunion Island: importers (n = 4), local supply chains (n = 4) and small independent producers (n = ~200). These suppliers used five retail channels to sell their products: supermarkets, butcher shops, cafés - hotels – restaurant (CHR), the mass catering sector (hospitals, canteens and other collective establishments) and direct sales. There were two salient competitors: importers and the local supply chain n°2; importers because 100% of their product is in competition with the local supply chain in this case study, and local supply chain n°2, because 10% of its volume is sold via supermarkets. The other competitors sell their products through different retail channels from those of the main supply chain. Depending on the threshold capacity of each competitor and projected demand, this situation will certainly evolve in the next ten years. According to the scenarios, there will be about 17.9 and 0.7 10^3 tonnes of product in competition between the supply chain under study and the importers and local supply chain n°2, respectively.

Table 13: Meat volumes supplied by competitors of the local poultry supply chain as a function of the competitor and its characteristics

N° of the supplier		0	1	2	3	4	5
Type		Importers	Local supply chain (under study)	Local supply chain	Local supply chain	Local supply chain	Independent producers
Volume produced	tonnes	17,920	8,609	670	50	250	3,596
Species	%	100	0	100	0	10	100
Retail channel in 2010 (%)	Supermarkets	100	80	10	100	100	0
	Butchers	0	0	86	0	0	0
	CHR	0	11	2	0	0	0
	Mass catering	0	9	0	0	0	0
	Direct sales	0	0	2	0	0	100
Volume in competition	tonnes	17920	0	656.6	0	25	0
Market share in 2010	%	66	32	2	0	0	0
Potential for expansion in the next 10 years	tonnes	Unlimited	+14,617	+5,000	0	0	Unknown

4.3.3. Community

The spatial distribution of the value-added created by the poultry supply chain showed that 78% of the total value was shared by stakeholders in Reunion Island and 39% of this value-added was redistributed within the local community. Thus, consumption by collaborators and suppliers' employees supported 473 NMW equivalents in the community in Reunion Island.

4.3.4. Non-human stakeholders

Figure 16 presents the normalized results of the impacts of the supply chain activities. The spatial differentiation of impacts shows that, except for soil acidification (SA) and the formation of particulate matter (FPM), the majority of impacts occur outside the territory. Major concerns for Reunion Island are the two above impact categories (SA and FPM). At global scale, major concerns are freshwater eutrophication (FE) and ecotoxicity (FEC), marine eutrophication (ME) and ecotoxicity (MEC), terrestrial ecotoxicity (TE), human toxicity (HT), soil acidification (SA) and fossil fuel depletion (FD). Climate change (CC) and formation of photochemical oxidants (FPO) are poorly represented, which is consistent with results of studies comparing the impact of livestock products (de Vries and de Boer, 2010). As the use of poultry litter as organic soil amendment makes it possible to avoid importing mineral fertilisers and hence decrease the impact on climate change, these impact categories were not included in the following analysis.

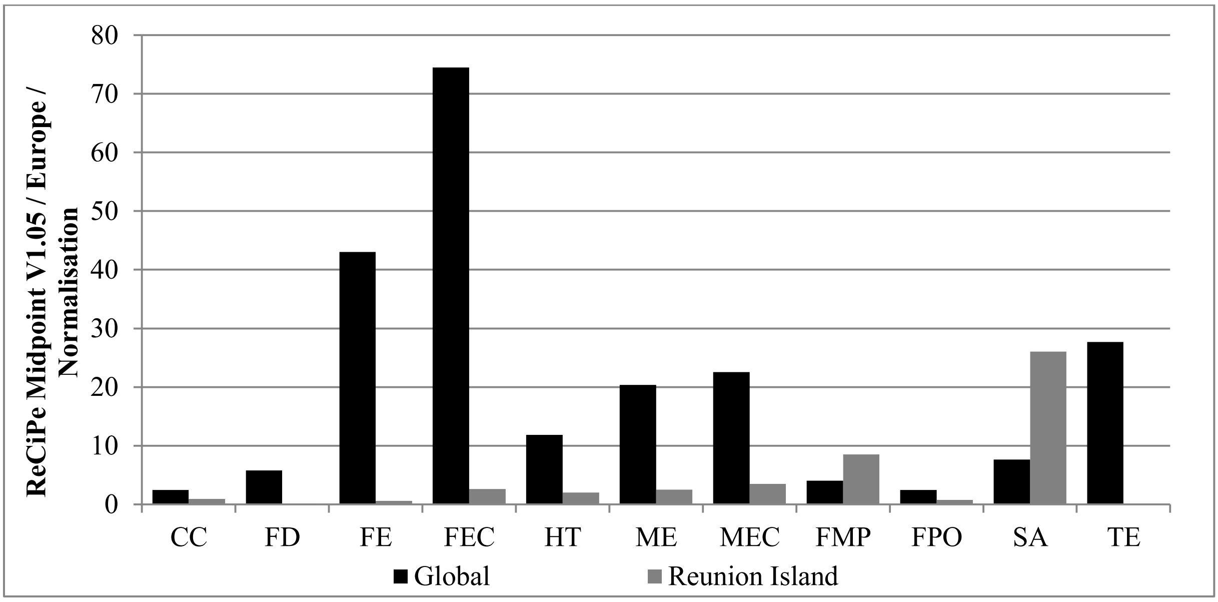

Figure 16 : Normalization and spatial differentiation of environmental impacts of the supply chain activities

CC: Climate change; FD: Fossil fuel depletion; FE: Freshwater eutrophication; FEC: Freshwater ecotoxicity; HT: Human toxicity; ME: Marine eutrophication; MEC: Marine ecotoxicity; FPM: Formation of particulate matter; FPO: Formation of photochemical oxidants; SA: Soil acidification; TE: Terrestrial ecotoxicity

Figure 17 shows the relative contribution of the suppliers to the total impact in the nine selected impact categories. In each bar, suppliers are ranked according to their contribution to total impact. In the graph legend, different patterns are used for the three main contributors. Other contributors are in shades of grey.

In Reunion Island, only two suppliers (poultry breeders and the electricity supplier) contribute more than 95% to each selected impact category (formation of particulate matter and terrestrial acidification). In the case of poultry breeder farms, ammonia emissions from poultry manure are precursors of secondary particle matter that cause acidification when they are re-deposited on the soil and to respiratory problems when they are inhaled (Asman *et al.*, 1998). In the case of the electricity power plant, direct emissions of primary particles discharged into the atmosphere are responsible for respiratory problems when they are inhaled.

At global scale, between two and five suppliers of electricity, maize, rice and soybean meal suppliers, and water contributed significantly to the total impact except for fossil fuel depletion, to which many suppliers contribute. For each impact category, a single supplier contributed more than 40% of the total impact. Concerning the supply of electricity, most impacts were due to pollutants emitted during the extraction of hard coal: phosphate for freshwater ecotoxicity, manganese for human toxicity and nickel for marine ecotoxicity. In the case of maize, soybean and rice, the impacts are mostly caused by phosphate in the case of freshwater eutrophication, to chemical substances (pesticides) emitted into soil and water in the case of freshwater and marine ecotoxicity and human toxicity.

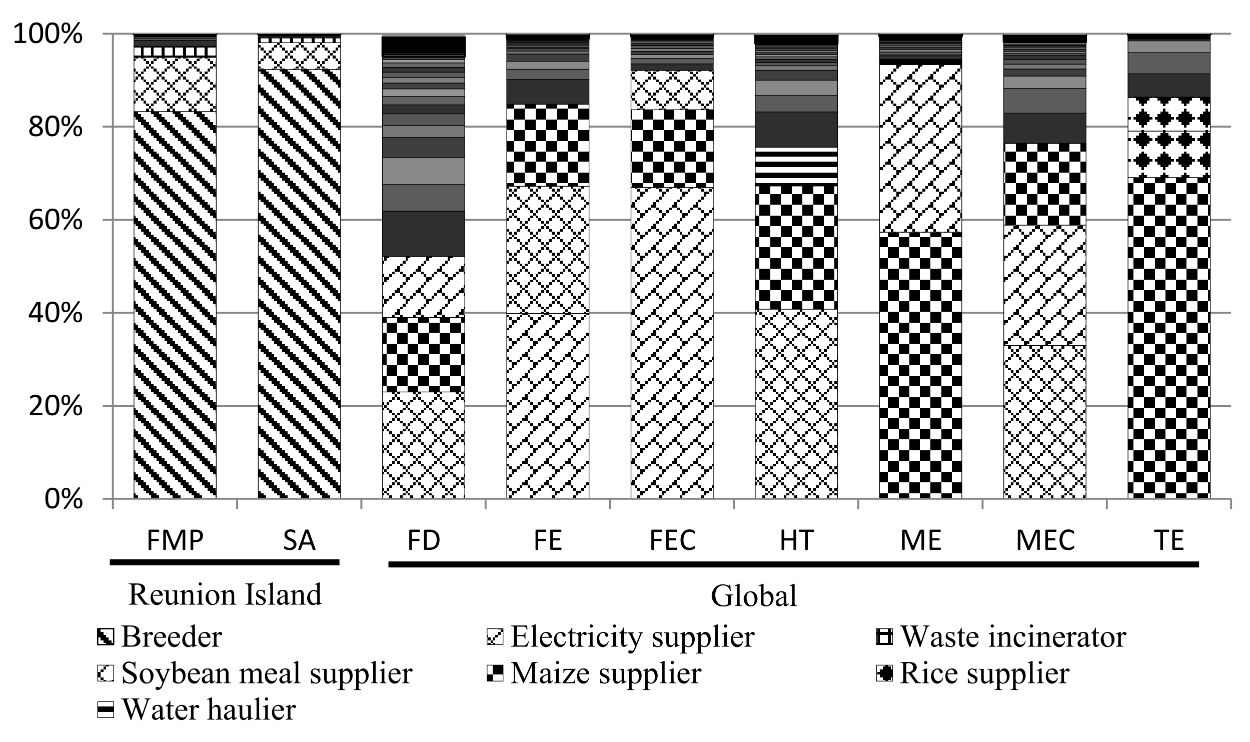

Figure 17: Relative contribution of each type of supplier to each environmental impact category

4.4. Changes in the impacts of the supply chain in next ten years

Figure 18 and

Figure 19 present the effects of the supply chain on the selected stakeholders in 2010 (scenario "2010"), in 2020 without mitigation measures (scenario "2020") and in 2020 with mitigation measures (scenario "2020_IS"). Without mitigation measures, environmental impacts would increase by +70%. Without mitigation measures, creation of jobs in the 'supply chain industrial network' is +11.5% in Reunion Island and +40% at global scale. In the community, the increase in job creation would be about +22.5% in Reunion Island and +36.9% at global scale. If the three mitigation measures were implemented (scenario 2020_IS), environmental impacts would decrease by -7% to -25% depending on the category (see Figure 18). Conversely, the mitigation measures would cause job losses both in the 'supply chain industrial network' and in the community. The losses would range from -2.5% in the 'supply chain industrial network' in Reunion Island to -19.4% in the 'supply chain industrial network' worldwide.

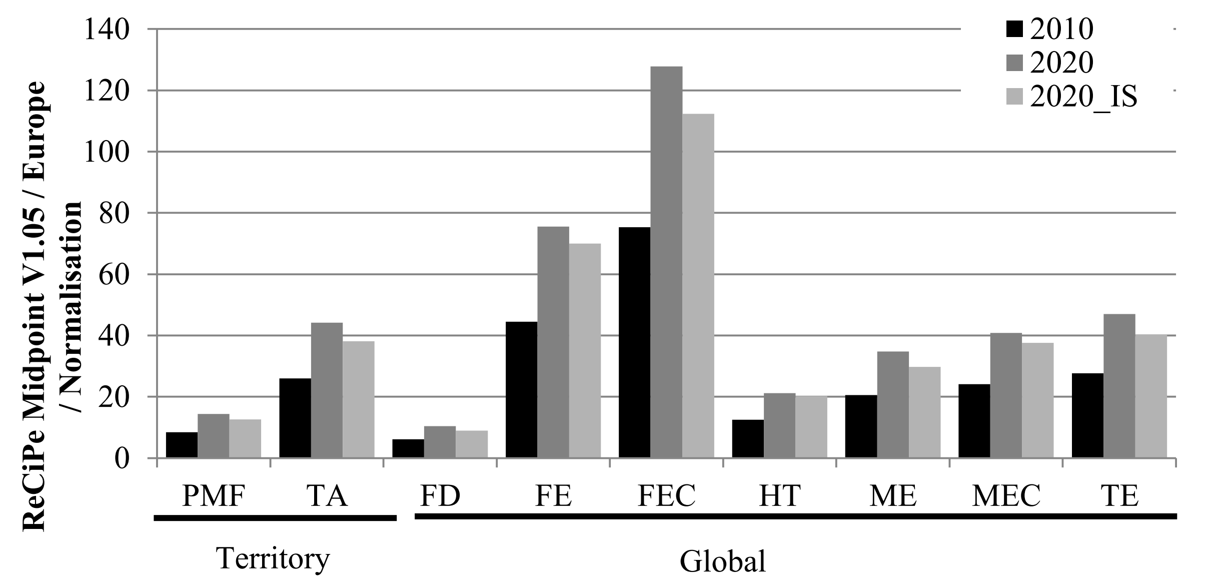

Figure 18: Normalization and spatial differentiation of environmental impacts of the supply chain activities in two scenarios (2020 and 2020_IS) with reference to the existing supply chain (2010).

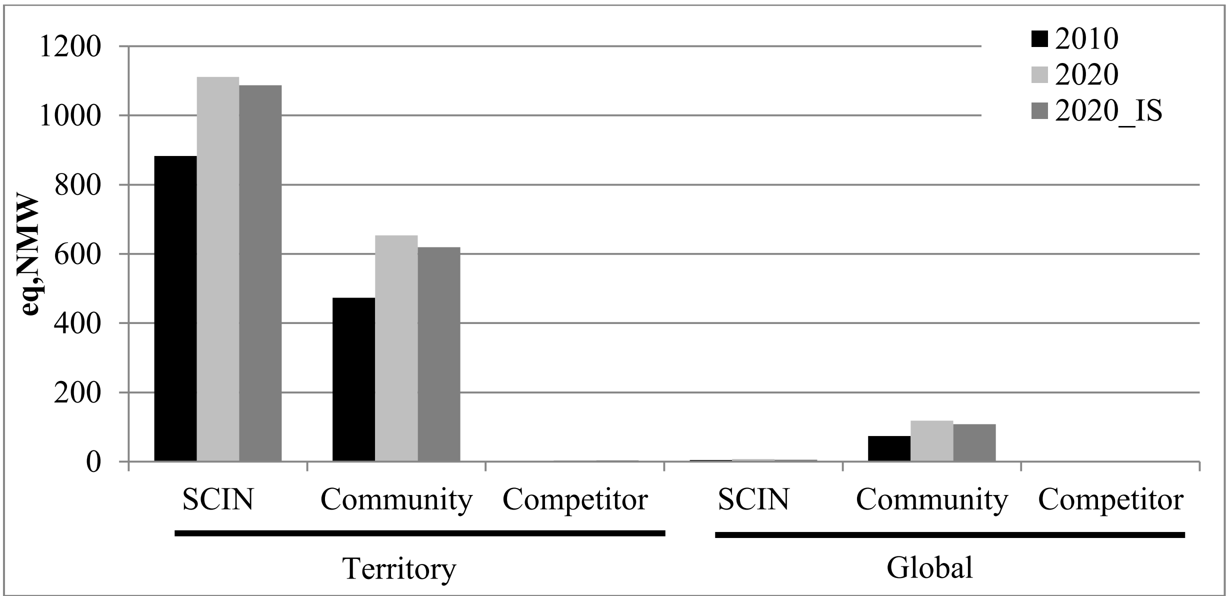

Figure 19: Spatial differentiation of the effect on employment within the community and the industrial sector in two scenarios (2020 and 2020_IS) with reference to the existing supply chain (2010).

Table 14 presents the changes in the different impact categories by 2020 if mitigation measures were implemented separately with reference to 2010 (scenario "2010"). Since *equipment upgrading* would increase electricity consumption for biogas and decrease it for solar panel, the reduction in environmental impacts would be almost zero in Reunion Island in the impact categories concerned. Improving *farm eco-efficiency* would have the highest reduction score among all impact categories i.e., between 10% and 16.5%, except for freshwater ecotoxicity and marine ecotoxicity because of the transfer of impacts due to increased electricity consumption by the farms (see §3.6). *Transport limitation* would improve the impact of marine ecotoxicity most but the effects of its combination with *equipment upgrading* and *farm eco-efficiency* would be limited because of the increase in electricity consumption due to the two other mitigation measures. The sum of the changes in each impact category of all measures does not match the relative contribution of all measures implemented together. For instance, for the impact category “fossil depletion”, the sum of the relative rates of change when the scenarios are implemented separately is 11.9%, whereas when all scenarios are combined, it is 8.5%. These results highlight interactions between mitigation measures. The ‘supply chain industrial network’ and community would both be affected by the *farm eco-efficiency* scenario. The community would also be affected by the *equipment upgrading* scenario. Competitors would not be affected since this stakeholder category is only concerned by the growth scenario.

Table 14 : Differences in the different impact categories by 2020 if mitigation measures were implemented separately or all together in comparison with 2010.

	Scenario	Equipment upgrading	Farm eco-efficiency	Transport limitation	All scenarios
Reunion Island	PMF	-1.1%	-12.3%	0.0%	-12.5%
	TA	-0.5%	-14.9%	0.0%	-15.0%
	SCIN	0.0%	-2.2%	0.0%	-2.2%
	Community	-2.4%	-3.1%	0.0%	-3.1%
	Competitors	0.0%	0.0%	0.0%	0.0%
Global	FD	-3.6%	-5.0%	-3.3%	-8.5%
	FE	-0.3%	-6.7%	-1.0%	-7.7%
	FEC	-0.2%	-13.2%	-0.4%	-13.6%
	HT	-0.7%	-2.2%	-2.0%	-4.1%
	ME	-0.9%	-14.2%	-3.5%	-18.2%
	MEC	-0.6%	-4.7%	-3.8%	-8.3%
	TE	0.0%	-16.5%	0.0%	-16.5%
	SCIN	0.0%	-19.4%	0.0%	-19.4%
	Community	-1.3%	-8.6%	0.0%	-8.7%
	Competitors	0.0%	0.0%	0.0%	0.0%

5. Discussion

The effects of the poultry supply chain on several stakeholders were quantified using a framework and methods described in a companion paper (Thévenot and Vayssières, 2013). Bearing in mind the objective is sustainable development, it is important to identify what makes these results useful for decision making by managers and what could facilitate a broader use of this work in other food systems around the world.

5.1. Useful results for decision making?

In most industrialized food supply chains, two kinds of decision makers have a major influence on the food system design: (i) firm managers because of the strategic choices they make at the firm or supply chain level, (ii) policy makers through the sectorial policies they create, which guide the decisions made by firm managers. In our case study, we chose to work with firms. No policy makers were involved in the assessment process (see §2.2). The value of the results was confirmed by firm managers. The results were used to collectively decide which mitigation measure should be implemented as a priority. Investments have already been made to improve farm eco-efficiency by reinforcing technical advisory staff. Upgrading equipment was identified as the second priority; this process is just beginning and will be completed by 2015. Transport limitation was abandoned. The results were used by the focal firm to communicate their environmental efforts to consumers (through a website) and to defend their development strategy before the European Union in Brussels, to justify subsidies.

Three keys points were cited by managers as making the results useful: (i) the spatial differentiation of results, (ii) the multi-criteria dimension of the analysis and (iii) the simplification of results through the aggregation of indicators.

The spatial differentiation of results underlines the distribution between territories (Reunion Island versus global) of the calculated effects and also of predicted changes in these transfers depending on the mitigation and growth scenarios chosen. These results directly inform managers how their firm contributes to territorial equity with respect to others. Through their choice of suppliers and the firm's interactions with them, the manager has several potentially complementary ways to improve the firm's or the supply chain's sustainability performance (Walton *et al.*, 1998; Lippmann, 1999; Vachon and Klassen, 2008). In the case where firms are closely linked, i.e. salient suppliers, the firm managers can try and persuade their suppliers to improve their practices. If a firm has no significant influence on its suppliers, the manager can switch to another supplier with better performances. In the case of the poultry supply chain studied here, most impacts on the environment take place outside the territory of poultry production (78% on average among all impact categories, see Figure 18). From two to five firms are responsible for 75% of the total impact, depending on the category. These are generally grain traders who buy raw materials (i.e. maize, soybean and rice) on the international market to produce livestock feed. These firms also supply bigger livestock sectors in mainland France than in Reunion Island. The demand in Reunion Island consequently does not play a determining role in the decision making of those firms. The majority of the environmental impacts of the supply chain are due to raw materials that are exchanged on the world market by firms who are not defined as salient suppliers for the poultry supply chain studied here. Changing suppliers is also unlikely because there is no other competitive source of supply than Argentina for soybean meal or for cereal crops because a subsidy for cereals reduces the cost of importing from Europe. The only way for the poultry supply chain to reduce its impacts would be to introduce drastic measures to improve the eco-efficiency of processes related to cereal and soybean consumption along the supply chain. Conversely, the effect of the poultry supply chain on employment in the community, the 'supply chain industrial network', and on competitors is would mainly be felt in Reunion Island (>99%) since most of the imported goods are purchased from multinational groups and most of the costs of imported poultry products are already amortised in mainland France. Changing to local suppliers, for instance, packaging providers would thus be the best sustainable strategy.

The multi-criteria assessment underlines the multiple transfers of effects between social and ecological stakeholders. These results directly inform the manager of the trade-offs that have to be made for each mitigation measure. For instance, several transfers would occur if the mitigation measure 'farm eco-efficiency' is adopted. Nitrogen volatilization, which has impacts on human and ecosystem health, depends on atmospheric conditions in the building. When broilers are not kept within their optimum temperature range they tend to use the feed concentrate inefficiently (more nitrogen is eliminated in litter in the form of faeces than used to build meat and increase body weight). Investment in equipment allowing better temperature regulation (ventilation and control device) and better farming practices (feeding strategy) would solve this problem. However, the gain in emission reduction would be partly offset by the increase in electricity consumption due to the ventilation equipment (e.g -5% for fossil depletion, see Table 14). Indeed, increasing electricity consumption in the territory would also increase pressure on fossil fuel resources outside the territory, and the emission of particulate matter within the territory. The implementation of this mitigation measure also negatively affects job creation throughout the industrial network of the supply chain and the community (

Figure 19) because of the decrease in the consumption of goods and services in the vicinity of the firms that produce animal feed. The second type of scenario concerning biogas production would also lead to trade-offs. The incineration of slaughterhouse wastes would affect the territory but to a lesser extent than the production of electricity. However, the firm responsible for incineration belongs to the industrial network of the supply chain. For this supplier, a change in supplier was simulated by the creation of a new activity: biogas. Results showed that biogas would be of less interest in a country where the energy supply mix is mostly based on fossil energy. Electricity consumed to burn waste and the corresponding emissions of particulate matters would be partly offset by impacts linked to the increased consumption of electricity used to operate the biogas plant. This explains the low score for the formation of particulate matter in the biogas scenario.

Simplification by aggregating the results means a non-scientific audience can benefit. These results provide clear information about the sustainability of the supply chain over time. For instance, Figure 20 presents the relative improvement for salient stakeholders if mitigation measures were implemented separately by 2020 in comparison with 2010. In figure 5, the indicators listed in Figure 18 and

Figure 19 are aggraded in categories that are more easily understood by a non-scientific audience. All the mitigation measures would positively affect stakeholders of the ecological subsystem (human and ecosystem health and resources conservation) but negatively affect stakeholders of the social subsystem (reduction of job creation in the community and in the supply chain industrial network). Farm eco-efficiency is clearly the mitigation measure that would change the food system most. Human and ecosystem health and resources conservation would be significantly improved by this measure. The community and the supply chain industrial network would also be significantly (but negatively) affected. The other scenarios would have smaller effects on all stakeholders. Moreover the most affected stakeholders differ depending on the scale. For instance, within the territory, the farm eco-efficiency scenario would lead to a significant improvement in human and ecosystem health. At global scale, it would improve resource conservation and ecosystem health (in order of importance). These results highlight the complexity and importance of trade-offs between stakeholders, between a territorial and the global scale (including the transfer of impacts), and between mitigation measures (see table 4).

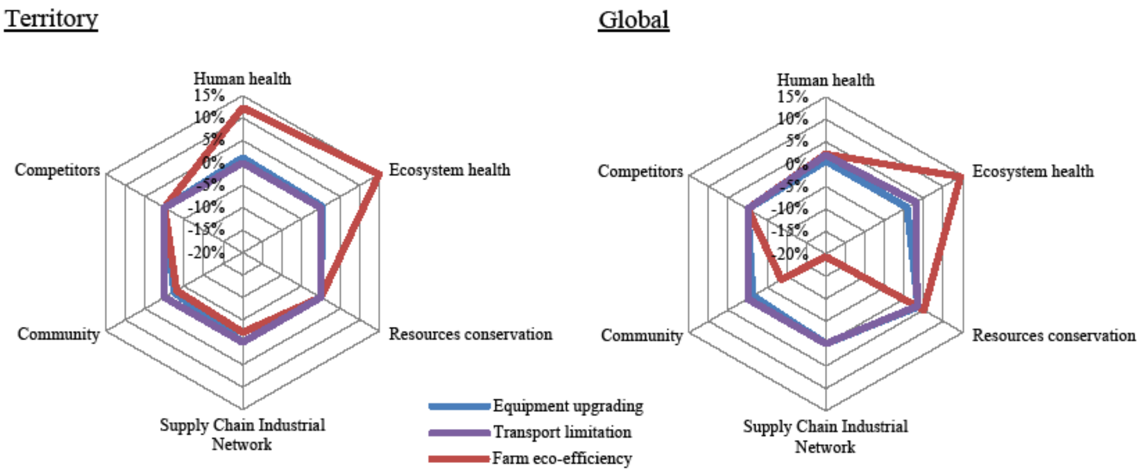

Figure 20: Comparative improvement for salient stakeholders (competitors, 'supply chain industrial network' and community job creation, human and ecosystem health, and resource conservation) per mitigation measure by 2020 in comparison with 2010.

5.2. A broader use of the proposed framework and methods?

The application of the framework was facilitated by certain specificities of the food system and territory (Reunion Island) studied. In the following, several of these specificities are highlighted and alternative options proposed with a view to the broader use of the framework for the assessment of other food systems around the world.

Given the particularities (narrowness and insularity) of Reunion Island, the definition of scope was simple in our case. Identification of the stakes and supply chain stakeholders was easy since most steps, from the chick breeding to sale of the finished product, rook place in the same territory. However for case studies located, for exemple, in Europe, the globalisation of food firms tends to render suppliers more anonymous and relationships between producers and retailers more ephemeral (Testa, 2011). This may considerably complicate the identification of stakeholders and stakes. In this study, we had access to a regional account which allowed us to calculate results for specific sites. Regional accounts are available for most countries around the world, but the uncertainties might be larger in developing countries. Indeed international accounting standards are still not applied everywhere, given the difficulty involved in collecting and aggregating the data required to construct such accounts (Zeghal and Mhedhbi, 2006). Moreover, input-output accounts are rarely available at regional level (except for European ultra-peripherical territories like Reunion Island) and there may be major inequalities and disparities between neighbouring regions. The regional input-output tables has been applied to sub-national geographic units since the 1950s (Isard, 1951) but this construction requires the collection of considerable additional data to determine interregional trade flows (Sargento, 2009), which explains why it is not widely used.

The detailed production-expenditure accounts of all the local firms of the supply chain were important sources of data for our assessment. The poultry supply chain used in the present study is vertically integrated and well organised thanks to a clear division of tasks and to the support of an inter-professional association. This pattern and the resulting clear communication between firms considerably facilitated access to these data. Moreover the accuracy of the accounts made it possible to cross-check data sources provided by firms (expenditure accounts) with data provided by their suppliers (production accounts) and thus to check the coherence of data and reduce uncertainty. Informal supply chains based on low-input systems are still common in developing countries (Vitousek *et al.*, 2009). For instance, most fresh milk distribution networks around towns in West Africa are supplied by a large number of small dairy collectors linked to an even bigger number of dairy farmers with very variable farming practices (Coulibaly D. *et al.*, 2007). Many efforts have been made to group them to improve better milk quality (Poccard Chapuis R. *et al.*, 2007). The proposed methodology would be useful to accompany this transition in a sustainable way. Conducting a data inventory on this type of food system is a challenge because of the lack of quantitative data. The best option may be to conduct wide surveys with the many heterogeneous stakeholders. But uncertainty on data increases when an assessment is based on data provided by expert judgment (Goldstein and Hogarth, 1997). The participation of stakeholders, including farmers, in the whole assessment process (see §3.5), plays a crucial role in reducing this uncertainty, as underlined in the proposed framework (Thévenot and Vayssières, 2013).

6. Conclusion

In this paper, a framework designed to evaluate the contribution of food chains to the sustainable development of their territory was applied to the main poultry supply chain in Reunion Island. The main stakeholders of the supply chain were involved in a five-step assessment process including: (i) problem framing, (ii) the selection of relevant indicators and assessment methods, (iii) the definition of scenarios to be explored, (iv) data collection, and (v) the interpretation of the results. Results show that the supply chain externalizes most of its environmental impacts (due to its strong dependency on imports of raw materials), whereas it internalizes most of its contribution to socio-economic impacts within the territory (due to the location of the main production and processing facilities on the island). Analysis of the scenarios provided a dynamic view of the future of the supply chain and insights into the potential effectiveness of some mitigation measures proposed by the stakeholders. The improvement in farm eco-efficiency was the measure that would change the supply chain most. Spatial differentiation of impacts, multi-criteria assessment and grouping indicators into more generic categories appear to be key features that make the analysis particularly useful for decision making for firm managers. In fact, the spatial differentiation of impacts revealed the extent of impact transfers between territories, multi-criteria assessment underlined several trades-off between environmental and socio-economic impacts, and grouping indicators facilitated interpretation of the results by non-scientists. Further studies on different food chains in a broader context are now needed to test the genericity of the framework. The fact that the poultry supply chain concerned is highly integrated and based on high-input farming systems, and that it supplies a narrow European island territory strongly influenced the choice of the method for data collection. Studying informal supply chains based on low-input farming systems, like those mostly encountered in developing countries, would involve adapting data inventory methods. These could be based on broader surveys. In this case, the participation of stakeholders in the whole assessment process would be even more important, in particular to reduce the uncertainty on data and results.

Discussion Générale

La forme de ce manuscrit *sur article* nous a conduit à discuter les principaux résultats du travail de thèse au fil des précédents chapitres. Dans le chapitre 1, nous avons montré l'avantage d'une approche transdisciplinaire pour délimiter les frontières du système à évaluer, et l'importance d'une intégration des méthodes d'évaluation afin de capter les dynamiques simultanées du système social et du système écologique. Dans le chapitre 2, nous avons discuté de l'intérêt d'ingérer une analyse multivariée à l'étape d'inventaire de l'ACV dans le but de mieux relier le fonctionnement des exploitations aux impacts environnementaux et ainsi pouvoir promulguer des recommandations spécifiques et adaptées. Dans le chapitre 3, nous avons montré la pertinence de la méthode des effets pour évaluer les effets socio-économiques d'une filière. Ces deux méthodes, ACV et méthodes des effets, sont apparues compatibles avec le cadre conceptuel proposé en chapitre 1. En effet, certains points méthodologiques communs sont intéressants à conserver comme notamment le cycle de vie des produits dans la délimitation du périmètre dans le système écologique (ACV) et la remontée des chaînes dans la délimitation du périmètre dans le système social (méthode des effets) dans lesquels est insérée la filière, la spatialisation des consommations et des émissions (ACV) et des consommations intermédiaires (méthode des effets) pour séparer les effets sur le territoire et dans le reste du monde, et enfin les différentes utilisations possibles des taux inclus (méthode des effets) et des substances (ACV) pour caractériser les effets sur les différentes parties prenantes. Enfin, dans le chapitre 4, nous discutons, dans un premier temps, de la capacité du cadre conceptuel adapté au cas de la filière agricole réunionnaise à fournir des résultats pertinents et utilisables par les décideurs des filières. Dans un second temps, les concepts et méthodes retenus, découlant ou non des particularités du cas d'application, sont confrontés à d'autres filières afin de mettre en avant les perspectives et les limites à une éventuelle adaptation.

Ainsi, dans ce chapitre nous cherchons à évaluer si le cadre conceptuel proposé permet de répondre aux attentes des deux principaux partenaires du dispositif CIFRE : l'entreprise (Crête d'Or Entreprise) et le laboratoire de recherche (CIRAD).

Pour l'entreprise, ce dispositif a pour vocation d'augmenter son potentiel d'innovation grâce à la réalisation de recherches universitaires à partir de ses propres contraintes industrielles. Plus particulièrement, la finalité attendue de cette thèse était double: 1) situer la filière par rapport aux enjeux territoriaux en matière de développement durable afin d'élaborer une stratégie de progression pour les 10 années à venir, 2) dégager un avantage concurrentiel par l'anticipation des futures obligations règlementaires en termes d'affichage environnemental, mais également de fournir des arguments chiffrés pour la défense des intérêts de la filière face à la concurrence extraterritoriale.

Pour le laboratoire scientifique, la finalité de ce travail était le renforcement des partenariats avec les entreprises locales par la valorisation de travaux innovants en milieu tropical, mais également le développement d'une méthodologie originale pour l'évaluation de la durabilité des filières, transférables à d'autres territoires, tropicaux en particulier. Dans un deuxième temps, nous discuterons donc du niveau de généricité du cadre conceptuel en vue de son application à d'autres territoires.

1. Pertinence du cadre conceptuel vis-à-vis des attentes de la filière étudiée

La popularité croissante du concept de développement durable a fortement accru le besoin de l'opérationnaliser. En d'autres mots, de le rendre utilisable, mesurable et politiquement pertinent (Nijkamp and Ouwersloot, 1997). De nombreuses disciplines s'étant penchées sur la question, le concept de développement durable a connu une importante diversité d'interprétations. Notre question de recherche cherchant à placer la filière dans un contexte de développement territorial, nous a amené à mobiliser deux approches: l'approche géographique et l'approche par le management stratégique. Ces approches ont fait l'objet d'une littérature abondante. L'approche géographique s'est attachée à donner une dimension territoriale, régionale, voire urbaine au développement durable (Camagni *et al.*, 1998; Nijkamp *et al.*, 1991; Theys, 2002; Zuindeau, 2002) tandis que l'approche par le management stratégique s'est attachée à composer les objectifs financiers de l'entreprise avec ses nouvelles contraintes environnementales et sociales (Seuring, 2013).

Dans le cadre conceptuel développé, nous avons croisé ces deux approches afin d'aboutir à un outil qui soit à la fois pertinent pour les décideurs à l'échelle de la filière, mais également pour les décideurs de politiques sectorielles à l'échelle du territoire. Concrètement, les approches classiquement utilisées en management stratégique des entreprises ont été mises en œuvre dans le cadre théorique d'une évaluation de la durabilité à l'échelle territoriale (cf. Chapitre 3).

Appliquée au territoire, l'opérationnalisation du développement durable se traduit par une gouvernance permettant d'éviter un déclin économique, l'instabilité sociale et la destruction des ressources naturelles (Devuyst *et al.*, 2001; Rotmans *et al.*, 2000). Selon Wiek and Binder (2005), un outil d'évaluation multidimensionnel est nécessaire pour parvenir à la mise en place de cette gouvernance. Afin d'aboutir à un outil opérationnel pour les décideurs, plusieurs auteurs proposent une démarche permettant la construction d'un cadre conceptuel pertinent. Cette démarche se décline en trois dimensions dont les lignes directrices incluent : un concept directeur normatif opérationnalisé sur des enjeux spécifiques au territoire (dimension normative), une modélisation du système orientée pour l'évaluation de ces enjeux (dimension systémique), une procédure appropriée pour intégrer les parties prenantes pertinentes et relier les aspects normatifs et procéduraux (dimension procédurale) (Wiek and Binder, 2005; Binder *et al.*, 2010). Cette démarche a été mise en œuvre par Binder *et al.* (2012) à l'échelle du secteur laitier suisse et appliquée *a posteriori* sur différentes méthodes d'évaluation de la durabilité (Binder *et al.*, 2010). Nous proposons ici de vérifier que le cadre conceptuel développé dans le cadre de cette thèse et appliqué à l'étude de cas de la filière avicole réunionnaise s'inscrit bien dans les trois dimensions citées précédemment.

1.1. La dimension normative

Trois aspects doivent être considérés dans la dimension normative : le concept de durabilité utilisé, la définition des indicateurs qui en découlent et la méthode pour les évaluer (Binder *et al.*, 2010). Le challenge principal de cette dimension est l'application de la notion assez vaste de développement durable au système étudié et en fonction des objectifs définis. Dans notre étude de cas, la théorie des systèmes socio-écologiques (Ostrom, 2009) a servi de base pour appliquer le concept de durabilité (cf. Chapitre 1§2). Cette théorie a l'avantage d'inscrire notre objet d'étude dans un référentiel spatial et temporel. Elle ouvre également un champ assez large pour qu'un nombre d'indicateurs importants puisse être dérivé en fonction du cas d'étude. Ainsi, la notion d'équité inter-générationnelle a été prise en compte par l'établissement d'un horizon temporel (de 10 ans) sur lequel est mesuré le progrès ou la régression de la filière par l'intermédiaire d'un panel d'indicateurs. L'objectif de la filière doit donc être de créer plus de valeur au temps t+1 qu'au temps t. Cet horizon temporel permet de rendre mesurable l'évolution de la filière vers cet objectif en y intégrant des scénarios d'amélioration. Une volonté supplémentaire de la filière était de prendre en compte la notion d'équité intra-générationnelle c.-à-d. aborder les problèmes d'équité avec les territoires voisins. Dans notre cas, l'établissement d'une différenciation spatiale des effets a permis de donner la balance des impacts entre le territoire et le reste du monde. La prise en compte de l'équité interterritoriale est encore peu retrouvée dans les méthodes d'évaluation de la durabilité rencontrées dans la littérature. Ainsi la méthode IDEA (à l'échelle de l'exploitation; voir Vilain (2008)) fait partie des seules avec la méthode SSP (Binder *et al.*, 2012) à inclure un indicateur permettant de la retranscrire.

Le deuxième aspect à considérer dans la dimension normative est la définition des indicateurs à évaluer. Dans un premier temps, un panel d'indicateurs disponibles a été construit à partir d'une revue bibliographique des indicateurs de durabilité sociale et économique, et des méthodes de caractérisation d'impacts environnementaux. Une présélection a été effectuée sur la base des facteurs d'instabilité sociale à La Réunion relevés dans la littérature et des résultats de l'étape de normalisation des impacts environnementaux de la filière (cf. Chapitre 4§3.2.2). L'étape de sélection et de validation de ces indicateurs par un groupe représentatif des personnes affectant ou étant affectés par la prise de décision est importante pour la pertinence des résultats d'une analyse multicritère à vocation d'aide à la décision (Sadok *et al.*, 2009a; Sadok *et al.*, 2009b). L'identification et la présélection ont donc ensuite été présentées aux parties prenantes identifiées comme pertinentes pour discussion et une liste hiérarchique d'indicateurs jugés pertinents pour la filière et pour la durabilité du territoire a été définie. De même, une liste, non exhaustive, des parties prenantes que les activités de la filière sont susceptibles d'affecter a été établie collectivement. Cette liste nous a permis de distinguer les humains (communauté), les écosystèmes, les ressources, et les entités sociales (communauté, environnement industriel, concurrence). Le cadre permet également l'évaluation d'autres indicateurs plus conventionnels (non présentés dans les articles, mais disponible dans l'outil) traduisant la performance économique de la filière (p. ex. EBE, rentabilité) et la contribution directe à la santé économique du territoire (impôt). La plupart des méthodes d'évaluation de la durabilité (IDEA, IASP, RISE, SAFE, voir (Wiek and Binder, 2005)) s'arrêtent à une définition théorique des indicateurs sans passer par une évaluation participative.

Le troisième aspect est la procédure d'évaluation. Dans notre cas, la durabilité de la filière est évaluée par rapport à la perte ou la création de valeur par rapport à la situation de référence sur les différents indicateurs définis. Des indicateurs intermédiaires permettent une analyse fine des effets de l'activité de la filière sur les parties prenantes. Ces indicateurs sont réservés à des fins de monitoring interne. Des indicateurs agrégés sont également construits sur la base de ces indicateurs intermédiaires afin de proposer des résultats synthétiques selon des critères plus génériques et plus facilement appréhendables par un public plus large (cf. Chapitre 4 §5.1).

1.2. La dimension systémique

La dimension systémique correspond à la démarche utilisée pour représenter le système étudié, c'est-à-dire l'identification et la sélection des acteurs qui le composent, l'identification des interactions entre eux et des flux échangés. Dans notre cas, le choix du concept de développement durable et des enjeux nous amène à devoir évaluer notre objet d'étude, la filière, sous l'angle de plusieurs disciplines (cf. Chapitre 1§8.1). Les référentiels cités précédemment nous ont fourni un support spatial pour mener l'identification des parties prenantes et *mapper* leurs interactions avec la filière, et également un horizon temporel pour évaluer la progression de la filière i.e l'évolution des flux (cf. Chapitre 1, Figure 2: Multiple interactions between a food chain and its environment across different scales and dimensions). Plusieurs méthodes fournissant des critères de coupures, ont été proposées pour resserrer les frontières du système après identification des parties prenantes (Chapitre 1§7). Ces méthodes sont construites selon les mêmes principes, celui de l'importance des relations entre parties prenantes. Elles permettent une véritable intégration des méthodes d'évaluation et la mise en cohérence des indicateurs construits sur la base d'un inventaire commun des flux monétaires et matériels. Cet aspect constitue une originalité forte du cadre conceptuel proposé dans cette thèse. En effet, la plupart des méthodes d'évaluation de la durabilité s'appuient sur une représentation définie du système, mais n'aboutissent pas à une réelle intégration des indicateurs (Morse *et al.*, 2001).

1.3. La dimension procédurale

Selon le modèle de transfert de connaissance dans lequel s'effectuent les travaux de recherche, le choix des concepts et des méthodes peut être fait de plusieurs façons. Il peut être basé sur la théorie pure ou construit de façon transdisciplinaire. Le dispositif CIFRE est un modèle dans lequel universitaires et partenaires industriels sont amenés à coopérer. Ce modèle de type « interaction sociale » vise une circulation multidirectionnelle de la connaissance entre chercheurs, intervenants et décideurs (Dagenais, 2006) et favorise donc des travaux de type transdisciplinaire où les perspectives des parties prenantes ont une place importante dans le processus d'élaboration des connaissances (Scholz, 2000). Dans notre étude de cas, des approches de type *top-down* et *bottom-up* ont été conduites successivement. L'approche *top-down* des enjeux du développement durable vers les parties prenantes a permis de prendre en compte les règles internes aux territoires (enjeux territoriaux) mais également les règles externes, c'est-à-dire traitant des relations avec les territoires voisins et le reste du monde (Ghorra-Gobin, 2008). Tandis que l'approche *bottom-up* a permis de faire remonter les attentes et les contraintes des parties prenantes de la filière et de celle qui gravite dans son environnement. Il a été montré que l'utilisation conjointe de ces deux types de procédure a plus de chances de correspondre aux attentes des différentes parties prenantes en jeu (Brandt *et al.*, 2013; Gasparatos *et al.*, 2009) et donc d'aboutir à un outil opérationnel. Cela s'est confirmé dans notre cas.

1.4. Principaux bénéfices pour les parties prenantes

En parallèle de la mise en œuvre du cadre conceptuel proposé en chapitre 1 et de l'évaluation proprement dite, la démarche normative, systémique et procédurale décrite ci-dessus nous a permis de développer un outil de type tableur adapté aux attentes de la filière avicole réunionnaise. La finalité d'un outil d'évaluation de la durabilité est d'accroitre la performance, l'attractivité, ou la pérennité de l'entreprise. Dans notre cas, l'outil a été développé sous Excel afin de le rendre paramétrable et manipulable par le service innovation des entreprises. Cet outil se base sur un inventaire de flux de nature matérielle et économique, désagrégés à partir des comptes des entreprises. Le paramétrage se fait à partir d'une base existante, concrète et déjà régulièrement manipulée par les entreprises. Au cours de l'année 2014, cet outil a permis entre autres: i) de réaliser l'affichage environnemental d'une partie des produits de l'entreprise (cf. Appendice 6), ii) de fournir une argumentation chiffrée pour appuyer le dossier d'enregistrement d'installation classée pour la protection de l'environnement (ICPE) nécessaire à l'installation d'un méthaniseur (comparaison des gains en termes d'impact environnemental de la méthanisation des déchets d'abattage par rapport à leur incinération), iii) et enfin un appui chiffré des emplois générés par la filière sur le territoire réunionnais lors de négociations d'aides européennes à Bruxelles.

1.5. Perspectives méthodologiques

La dimension normative, systémique et procédurale de notre démarche nous a permis d'aboutir à un outil d'évaluation de la durabilité pertinent du point de vue de l'ensemble des parties prenantes ; cependant, plusieurs limites peuvent être soulignées en référence au cadre conceptuel proposé en chapitre 1. Ce cadre est volontairement ambitieux et certaines dynamiques, inhérentes au système socio-écologique, décrites dans le chapitre 1 n'ont en effet pas été évaluées dans l'application du cadre conceptuel sur notre cas d'étude dans le chapitre 4 et cela pour trois raisons principales.

Premièrement, certaines de ces dynamiques ne sont pas évaluables quantitativement de façon simple, car elles opèrent sur le long terme. Par exemple, les boucles de rétroaction impliquées dans la baisse de rendement des productions agricoles consécutives à une pollution des sols sont bien connues (Clancy, 2013). Bien que leur importance soit capitale pour évaluer la durabilité des systèmes agricoles sur le long terme (Sundkvist *et al.*, 2005), leur prise en compte requiert une étape de modélisation complexe et spécifique qui dépassait les objectifs de ce travail. Les avancées récentes sur les notions de résilience, de vulnérabilité et de capacité adaptative des systèmes socio-écologiques laissent entrevoir pour le futur une meilleure prise en compte des externalités négatives des systèmes de production (Darnhofer *et al.*, 2008; Kinzig *et al.*, 2006; Gallopín, 2006).

Deuxièmement, les méthodes d'évaluation sélectionnées sont encore des sujets actifs de recherche sur de nombreux aspects. Par exemple, dans notre cas d'étude, les services aux entreprises (p. ex. banques, assurances) occupent une partie importante des consommations intermédiaires. Ces services sont reconnus pour avoir des impacts non négligeables sur les ressources fossiles et sur les émissions de gaz à effet de serre (Rosenblum *et al.*, 2000). Des obstacles méthodologiques persistent cependant quant à la définition de l'unité fonctionnelle et du périmètre du système pour les évaluer. Plusieurs études ont tenté de contourner le problème à l'aide d'ACV hybride basée sur des tableaux Input-Output, mais de larges incertitudes persistent (Junnila, 2006; Shrake *et al.*, 2013). Aucune base de données ne permet donc actuellement de prendre en compte ces services. Leur non-prise en compte conduit à un certain décalage entre les périmètres d'évaluation des indicateurs.

Troisièmement, la territorialisation de l'évaluation amène à spatialiser les impacts. En analyse de cycle de vie, cette spatialisation est toujours en cours de développement afin d'améliorer la précision des évaluations (Potting and Hauschild, 2006). Dans notre étude, nous avons spatialisé géographiquement les consommations et les émissions, mais leurs impacts associés n'ont pas été évalués de façon site-spécifique. Par exemple, les émissions d'ammoniac des élevages avicoles ont un impact sur l'acidification du sol et l'eutrophisation des eaux. L'intensité de cet impact dépend largement de la composition des milieux qui reçoivent ces émissions (Meda, 2011). La spatialisation de cet impact, par exemple à l'île de La Réunion, requiert donc de passer par des facteurs de caractérisation plus fins (de site-générique à site-spécifique) (Huijbregts *et al.*, 2000). La méthodologie associée est cependant toujours en cours de développement et ne permet de caractériser ces impacts qu'au cas par cas.

2. Généricité du cadre conceptuel

Malgré ces quelques limites, le succès à La Réunion de la mise en œuvre du cadre conceptuel proposé dans cette thèse permet d’envisager son application à d'autres filières, d'autres systèmes d'élevage sur d'autres territoires. Le CIRAD est actif dans de nombreuses parties du monde où des acteurs du développement local pourraient appuyer ce développement par l'utilisation d'outils d'aide à la décision tels que celui développé au cours de cette thèse. Dans cette deuxième partie, nous proposons de caractériser le niveau de généricité[2] du cadre conceptuel proposé en évaluant qualitativement le degré d'adéquation des différents concepts théoriques et méthodologies sous-jacentes vis-à-vis de différents systèmes alimentaires dans le monde.

Dans les années 1990, le concept de filière, définissant l'ensemble des séquences d’activités et des modes de coordination qui permet la mise à disposition d'un produit sur le marché (Parent, 1979; Labonne, 1987) s’est étendu au concept de système alimentaire, *food system* en anglais. Ce dernier présente trois propriétés: morphologique (réseau d'acteurs liés par des flux), spatial (flux traversant des territoires) et dynamique (flux interdépendants) (Jean-Louis Rastoin and Gérard Ghersi, 2010).

2.1. Les systèmes alimentaires dans le monde et la filière avicole réunionnaise

Au cours de notre analyse, nous avons pu observer que les caractéristiques de la filière avicole réunionnaise étaient interdépendantes avec les dimensions identitaires, matérielles et organisationnelles du territoire réunionnais (cf. Chapitre 4). Interdépendantes, car le territoire a façonné la filière avicole telle qu’elle est actuellement. En retour, la filière avicole a contribué à façonner le territoire réunionnais. On observe de ce fait, dans l’agriculture réunionnaise, d’autres filières de production animale ayant des caractéristiques similaires. C’est le cas entre autres des filières porcine, bovin viande, bovin lait. En revanche les filières animales réunionnaises présentent de grandes différences avec celles présentes dans d'autres pays proches de la zone Océan Indien (p. ex. Mayotte, Madagascar). A l'échelle mondiale, il existe donc probablement autant de configurations possibles que de spécificités locales (Benko *et al.*, 1996). Malgré cette diversité, de grands ensembles d'organisation peuvent être distingués. Plusieurs types de classifications peuvent être retrouvés dans la littérature (Gereffi *et al.*, 2005; Soullier, 2013; J.L. Rastoin and G. Ghersi, 2010) en fonction de l’approche sur

[2] La généricité est le fait, pour un objet, de pouvoir être utilisé en l'état dans différents contextes.

laquelle repose le concept de filière (p. ex. supply chain, chaîne globale de valeur, méso-économie des filières) (Temple *et al.*, 2011). Notre approche correspondant plus à une approche de type méso-économie, nous proposons d'utiliser la typologie selon J.L. Rastoin and G. Ghersi (2010). Dans cette typologie, les systèmes alimentaires peuvent être classés en cinq grands types (Colonna *et al.*, 2011):

- *Le système domestique:* est le modèle de production alimentaire majeur et premier pourvoyeur d'emplois au niveau mondial (HLPE, 2013). La consommation se fait sur le lieu de production, le plus souvent dans un cadre familial (un ou plusieurs ménages).
- *Le système de proximité:* rassemble des filières courtes (faible nombre d'intermédiaires). La valeur ajoutée créée est réintégrée à proximité des activités de production (Chabault, 2006). Ces systèmes sont caractérisés par la proximité géographique des unités de production et de commercialisation qui génère une dynamique d'ensemble (Gilly, 1987).
- *Le système vivrier territorial:* est le modèle de production où l'approvisionnement entre les zones de production et les zones de consommation d'un même territoire (ville/campagne) est assuré par des réseaux d'échanges sur contrats souvent informels (Chaléard *et al.*, 2002). Ce type de système est caractéristique de l'Afrique de l'Ouest.
- *Le système agroindustriel:* correspond au modèle de production « *qualifié d'intensif, spécialisé, concentré, financiarisé et en voie de globalisation* » (Rastoin, 2006). La production est destinée au marché de masse et le nombre d'intermédiaires peut être important.
- *Le système de qualité différenciée*: corresponds à un modèle de production visant une stratégie concurrentielle de différenciation par la qualité (p. ex. certification d'origine, naturaliste, éthique, ou gustative) (Valceschini and Mazé, 2000).

On retrouve potentiellement ces types de systèmes partout à travers le monde, mais dans des répartitions différentes selon les territoires. De même, de nombreux systèmes alimentaires peuvent se retrouver à cheval sur deux ou plusieurs grands types de systèmes. Aucun de ces systèmes ne peut être qualifié *a priori* de durable. Les modalités généralement rencontrées dans ces systèmes alimentaires sont présentées dans la Table 15.

Table 15 : Principales caractéristiques (non exhaustives) des systèmes alimentaires rencontrés dans le monde

Variables\Système	Domestique	De proximité	Vivrier territorial	Agroindustriel	De qualité différenciée
Circuit	Court	Court	Court	Long	Court à long
Composition	Famille	Producteurs	Famille, Producteurs	Producteurs	Producteurs
Ressources financières	Micro-crédit	Cotisations, crédits, subventions	Cotisations, crédits	Cotisations, crédits, subventions	Cotisations, crédits, subventions
Activités	Production	Production	Production, collecte	Production, collecte	Production, collecte
Structure des exploitations	Intégration agriculture-élevage, pluri-culture	Pluriculture	Pluriculture	Monoculture-élevage	Monoculture, pluriculture
Technologies utilisées	Artisanale	Artisanale	Artisanale	Industriel	Artisanale, Industriel
Organisation du travail	Familiale	Familiale, salariale	Familiale, Salariale	Salariale	Salariale
Utilisation des revenus	Redistribution	Redistribution, investissements collectifs	Redistribution, investissements collectifs	Capitalisation	Capitalisation, non profit
Mode de coordination des agents	Aucune	Marché	Marché	Quasi-intégration	Marché, Quasi-intégration
Mode de création	Endogène	Endogène	Endogène	Exogène	Endogène, exogène
Encadrement	Privé	Public, Privé	Public, Privé	Public, Privé	Public, Privé
Modes de régulation	Prix du marché	Prix du marché	Prix administrés, relations contractuelles	Prix du marché, relations contractuelles	Prix du marché
Concurrence	Aucune, Concurrence parfaite	Oligopole bilatéral	Concurrence parfaite	Oligopole	Oligopole bilatéral
Espaces de références	Local	Local, régional	Régional	National, international	Régional, national
Horizons temporels des acteurs	Court	Court	Moyen	Long	Moyen à long

Source : (Jean-Louis Rastoin and Gérard Ghersi, 2010; Hugon, 1988; Terpend, 1997)

Le système alimentaire avicole réunionnais peut être classé à cheval sur le système de proximité et le système agroindustriel. En effet, de par son insularité, la quasi-totalité de la valeur ajoutée créée par la filière est réintégrée dans l'économie réunionnaise comme on a pu le voir dans le chapitre 3. De plus, la filière est relativement courte puisqu'il n'y a pas d'intermédiaires entre les activités de production (p. ex. pas de passage par des centrales d'achat). En revanche, la filière possède certaines caractéristiques du système agroindustriel. Par exemple, plus de 95% de la production se fait en bâtiment sans parcours et dans des exploitations spécialisées sur une seule souche de volaille (poulet blanc). De plus, l'approvisionnement en céréales se fait sur le marché mondial. Enfin, la coordination est quasi intégrée (verticalement) et une interprofession assure la régulation des prix pour répercuter les aléas du marché sur l'ensemble des acteurs de la filière, de la grande distribution à la fabrication de l'aliment concentré.

2.2. Applicabilité du cadre conceptuel sur deux exemples de systèmes alimentaires

Pour tester le niveau de généricité de notre cadre conceptuel, nous proposons de vérifier son applicabilité à deux exemples de systèmes alimentaires, l'un pouvant être classé dans les systèmes alimentaires vivriers et de proximité: l'approvisionnement en lait de la ville de Sikasso au Mali (Coulibaly D. *et al.*, 2007), et l'autre le groupe Doux pouvant être qualifié d'*hyper-groupe* dans les systèmes agroindustriels (Rastoin, 1992). La Table 16 rappelle les principaux concepts utilisés et suggère leur niveau d'applicabilité pour les deux exemples de filières décrits ci-dessous.

Table 16 : Principaux concepts théoriques mobilisés dans le cadre conceptuel et applicabilité à la filière laitière Malienne et la filière avicole Bretonne

Etapes	Thèmes	Théories, Concepts, méthodes	Référence	Filière Mali	Filière Bretonne
Concepts directeurs	Développement durable	- Théorie des systèmes socio-écologiques	(Ostrom, 2009)	++	+
	Stratégie des entreprises	- Création de la valeur partagée	(Porter and Kramer, 2011)	-	++
		- Théorie des parties prenantes	(Freeman, 1984)	-	++
	Définition des enjeux	- Théorie de la hiérarchie	(Allen and Starr, 1982)	++	-
	Construction de la connaissance	- Modélisation d'accompagnement	(ComMod, 2005)	+	++
Concepts modélisation du système	Identification des parties prenantes - Système social	- Théorie de l'avantage concurrentiel	(Porter, 1986)	-	++
		- Arène stratégique	(Bidault, 1988)	--	++
	Sélection des parties prenantes - Système social	- Théorie de la dépendance des ressources	(Pfeffer and Salancik, 1978)	--	++
		- Théorie des jeux	(Grandval and Hikmi, 2005)	--	++
	Identification des parties prenantes - Système éco.	- Limites planétaires	(Rockstrom *et al.*, 2009)	++	++
	Sélection des parties prenantes - Système éco.	- Méthode de caractérisation des dommages	(Goedkoop *et al.*, 2009)	++	++
Méthodes d'évaluation	Evaluation des indicateurs socio-économiques	- Analyse coût bénéfice - Méthode des effets	(Chervel *et al.*, 1997)	+	++
	Evaluation des indicateurs environnementaux	- Analyse de cycle de vie environnementale	(Guinee *et al.*, 2011)	++	++

-- Pas du tout applicable; - Applicable mais peu pertinent; + Applicable mais nécessitant des adaptations méthodologiques; ++ Totalement applicable

L'approvisionnement en lait du marché urbain de la ville de Sikasso au Mali *(ou filière Mali)* était assuré en 2006 par environ 160 élevages répartis dans les 60 villages périphériques de la ville. Ces élevages peuvent être de type sédentaire ou transhumant avec ou sans complémentation alimentaire. Les enjeux pour ces éleveurs relèvent essentiellement de la conservation de leur espace pastoral mis en danger par, entre autres, la croissance démographique et l'urbanisation. Les enjeux pour le territoire sont principalement la sécurité alimentaire des populations agricoles et le maintien de la fertilité des terres en lien entre autres avec la disparition de la pratique de la jachère et une pression forte sur le parc arboré (bois de cuisine, affouragement des animaux).

L'approvisionnement du lait est assuré par quatre types de circuit de commercialisation pouvant être utilisés par les éleveurs de façon exclusive ou simultanée. Cette diversité génère neuf types d'acteurs différents (éleveurs, transporteurs, vendeurs, etc.) avec un nombre total d'environ 1300 acteurs tous types confondus (Corniaux *et al.*, 2007). La plupart des échanges se font sous forme de contrats de collecte qui assurent une coordination entre producteurs, collecteurs et transformateurs (Duteurtre, 2007).

L'application de la théorie des systèmes socio-écologiques est facilement réalisable dans le cas de la *filière Mali,* car la zone d'étude est relativement circonscrite et permet la mise en évidence des dynamiques principales opérant entre le système social et le système écologique. L'articulation des échelles locale et globale est également possible et permet de relier de façon cohérente les enjeux des acteurs du système alimentaire avec les enjeux territoriaux. La faible diversité des parties prenantes permet de les identifier facilement. En revanche, la multiplicité de petites structures à faible poids économique entraine une fluctuation plus importante des partenariats annulant sa pertinence en termes d'opérationnalisation. Les différentes méthodes de modélisation du système perdent de ce fait leur intérêt. Cette multiplicité et le caractère aléatoire de l'utilisation des circuits de distribution limitent également la possibilité de réflexion sur la création de la valeur partagée qui nécessite un engagement de l'ensemble des acteurs de la production. Des solutions à ces limites pourraient en revanche émerger facilement grâce à un fort ancrage du modèle de réflexion participatif. En effet, les démarches participatives sont pratiques courantes de par l'appui d'ONG pour le développement de ces filières depuis de nombreuses années. L'utilisation de typologie de systèmes de production (cf. Chapitre 2) et d'un modèle dynamique reliant l'ensemble des acteurs permettrait à l'avenir d'accompagner leur développement.

Le groupe Doux *(ou filière bretonne)* comprenait 22 sites de production en France (la majorité localisée en Bretagne), 11 à travers le monde, plus de 15 000 employés et environ 800 élevages en 2012. Les unités au Brésil ont permis au Groupe, par le rachat du groupe Frangosul, d'ouvrir sa production à l'exportation sur les marchés du Proche, Moyen et Extrême Orient où la majorité du chiffre d'affaires est réalisé (en partie grâce aux restitutions à l'exportation). Le Groupe gère la production depuis la culture des céréales jusqu'à la transformation des produits carnés et leur commercialisation. Les enjeux pour le Groupe sont essentiellement la rentabilité de ce modèle d'organisation dans un contexte de fin des subventions à l'exportation et face à une concurrence internationale où les coûts salariaux sont plus bas. Les enjeux pour le territoire sont les impacts environnementaux liés aux élevages et à la culture de céréales associées. Parmi ces impacts, on retrouve l'appauvrissement des sols en matière organique (céréaliculture), l'émission de GES, la contamination aux pesticides et nitrates (élevage hors-sol), et l'émission de particules fines.

La théorie des systèmes socio-écologiques est moins pertinente sur ce modèle d'organisation que sur ceux de la filière Mali et réunionnaise. En effet, l'implantation du Groupe dans plusieurs régions et pays génère une grande hétérogénéité dans les dimensions territoriales et donc dans les enjeux qui en résultent. Le découpage en plusieurs systèmes socio-écologiques est possible, mais demande le développement d'un grand nombre d'indicateurs et de méthodologies pour les évaluer. L'établissement d'une différenciation spatiale interne au Groupe et comprenant les sites de commercialisation permettrait d'alimenter une discussion intéressante sur les questions d'équité extraterritoriale. De plus, le poids économique du Groupe et l'existence d'une gouvernance globale rendent la réflexion sur la création de la valeur ajoutée et l'identification des parties prenantes relativement pertinentes. Les concepts permettant la modélisation du système et le calcul des indicateurs sont de ce fait applicables puisqu'ils ont été développés par et pour les grands groupes industriels. En contrepartie, le modèle de réflexion de type participatif est rarement rencontré dans des entreprises ayant un poids économique aussi considérable. La sélection des indicateurs à évaluer et des parties prenantes à prendre en compte en seraient donc moins démocratiques.

2.3. Disponibilité des données

La méthode d’analyse de cycle de vie environnementale et la méthode des effets sont des méthodes dont la phase de collecte des données est particulièrement lourde en termes de coût et de temps. Dans notre cas d’étude, cette collecte s’est déroulée de façon optimale grâce à la mise à disposition quasi immédiate des données de flux monétaires et matériels (p. ex. compte de production-exploitation, bilan carbone) par l'ensemble des acteurs de la filière. De même, le rapprochement avec la Faculté d'économie de la Réunion, nous a permis un accès au tableau entrée-sortie régionale. Enfin, le caractère insulaire de La Réunion nous a permis une comptabilisation des flux entrants et sortants du territoire plus aisée.

Conduire ce type d'inventaire sur d'autres filières comme celle mentionnée précédemment peut se révéler bien plus difficile. Par exemple, pour la *filière Mali*, le nombre de parties prenantes est important et les contrats qui les relient peuvent être de type informel, ou encore relativement éphémères. La meilleure option, celle couramment pratiquée dans ce type de cas, est le recours à un échantillonnage par enquête de terrain puis à une analyse typologique. Cependant l'incertitude s'accroit lorsque les données sont issues de sources à dire d'expert (Goldstein and Hogarth, 1997). De plus, même si la comptabilité nationale est disponible maintenant dans la plupart des pays, certains pays en voie de développement accusent toujours un retard pour se conformer aux standards internationaux (Zeghal and Mhedhbi, 2006). Une incertitude importante peut donc résulter de l'évaluation des revenus dégagés par les filières sur leur territoire. Pour la filière bretonne, la difficulté réside dans la quantité importante de données à gérer avec des origines géographiques différentes. Comme on l'a vu précédemment (cf. §1.5), la désagrégation de la comptabilité nationale à une échelle régionale est une tache relativement complexe qui ne peut être menée sur plusieurs territoires.

Avant l'application de ce cadre conceptuel à d'autres filières, une réflexion importante doit être menée sur la méthodologie d'inventaire de données et son impact en termes de choix des méthodes d'évaluation. La participation de l'ensemble des parties prenantes à la démarche d'évaluation est donc un élément clé à l'aboutissement d'outils cohérents et opérationnels.

Conclusion

La sécurité alimentaire dans un respect des écosystèmes planétaires et des sociétés humaines reste le grand défi des prochaines décennies. La réalisation de ce défi ne pourra se faire sans avoir repensé de façon profonde les façons de produire et d'approvisionner. Le rôle de l'évaluation est primordial dans la mise en place de solutions d'amélioration. C'est pourquoi le principal objectif de cette thèse était de répondre à la question du « *comment évaluer? »*.

Pour atteindre cet objectif, les acteurs de la filière et du territoire réunionnais ont été associés à la construction d'un cadre conceptuel et à son application en vue de leur fournir une évaluation *ex ante* de leur contribution, négative et positive, au développement durable de leur territoire. Le cadre conceptuel était basé sur l'ancrage de l'objet d'étude, la filière, dans le concept de système socio-écologique. Cette base a permis de donner à l'analyse un référentiel spatial pour aborder la notion d'équité intra-générationnelle, et un référentiel temporel pour aborder la notion d'équité inter-générationnelle. Une analyse stratégique des enjeux du territoire a ensuite permis de mettre en évidence les différents types de parties prenantes impliquées et appartenant aux systèmes social et écologique. Les parties prenantes de chacun de ces types ont été identifiées à l'aide de théories issues du champ du management stratégique et à l'aide de méthodes de caractérisation des impacts environnementaux. Parmi ces parties prenantes, seulement celles essentielles à l'opérationnalisation du cadre conceptuel ont été retenues en utilisant des critères de coupure basés sur l'intensité de la relation entre ces parties prenantes et la filière. Deux méthodes d'évaluation parmi un panel ont été sélectionnées afin de mesurer les effets de la filière sur ces parties prenantes. Dans un premier temps, ces méthodes d'évaluation ont été menées séparément afin d'identifier les perspectives de leur application sur notre objet d'étude, et de vérifier leur compatibilité avec le cadre conceptuel et les éventuelles adaptations à réaliser. Nous avons montré que l'analyse de cycle de vie environnementale était assez flexible pour être appliquée sur un système de type *filière*, pour spatialiser les impacts de l'activité évaluée et pour convertir monétairement une partie des flux de matière en vue de réaliser un inventaire commun. La méthode des effets, développée au départ pour l'évaluation de filières et l'étude de la distribution des effets locaux est également compatible avec notre cadre conceptuel. L'application conjointe du cadre conceptuel et des deux méthodes d'analyse a été réalisée avec succès. Les résultats montrent que la filière a fortement tendance à externaliser ses impacts environnementaux à cause d'une forte dépendance aux importations de matières premières. En revanche, la contribution aux indicateurs socio-économiques est plus marquée sur le territoire grâce à un recours important aux services locaux. L'analyse dynamique des résultats en incluant les scénarios de croissance et d'amélioration montre de nombreux transferts sujets à compromis entre les territoires et entre les indicateurs des deux systèmes. Ces travaux ont abouti au développement d'un outil de simulation paramétrable, et directement utilisable par la filière avicole réunionnaise. La discussion sur la pertinence de la démarche a permis de valider cet outil de simulation, mais a également mis en évidence certaines limites entre la conception du cadre conceptuel et la couverture de l'évaluation liés à des manquements méthodologiques. Les perspectives de recherche sur chacune de ces limites permettent d'envisager des améliorations au fur et à mesure des progrès de la recherche. L'évaluation du niveau de généricité sur deux autres filières a mis en évidence le potentiel d'application du cadre conceptuel à d'autres systèmes alimentaires. Cette première exploration de l'applicabilité des concepts est succincte et mériterait d'être approfondie en mettant en œuvre l'ensemble du processus.

Appendices

Appendice 1 : Terminologie

Les termes définis ci-dessous peuvent avoir plusieurs significations en fonction du domaine scientifique (sciences formelles, naturelles, humaines et sociales) et de la langue (anglais ou français) dans lesquels ils sont employés. Voici leur signification dans cette thèse.

Démarche scientifique – *Scientific reasoning*

Manière de conduire un raisonnement, de progresser vers un but par le cheminement de la pensée.

p. ex. *la démarche est déductive si le raisonnement est basé la construction logique et des schémas conceptuels ou inductive si le raisonnement est basé sur l'expérience ou l'observation.*

Approche scientifique – *Scientific approach*

Dans les disciplines scientifiques, il existe plusieurs courants théoriques pour aborder un problème. Le choix d'une ligne théorique constitue une approche.

p. ex. *l'opposition des approches hétérodoxes (institutionnalisme, théorie de la régulation, etc.) avec les approches orthodoxes (macroéconomie keynésienne, macroéconomie classique, etc.)*

Cadre conceptuel – *Conceptual Framework*

Schéma cohérent permettant d'organiser et de mettre en relation des idées, des concepts et des méthodologies afin d'atteindre les objectifs d'un projet de recherche.

Méthodologie – *Methodology* & Méthode (scientifique) - *Method*

Une méthodologie est un ensemble de méthodes régissant une recherche scientifique ou dans une exposition doctrinale.

Une méthode est un ensemble ordonné de manière logique de principes, de règles, d'étapes, qui constitue un moyen pour parvenir à un résultat

p. ex. *l'application de la méthodologie d'Analyse de cycle de vie passe par l'utilisation des méthodes de calcul d'inventaire du cycle de vie, des méthodes d'allocation des coproduits, et des méthodes de caractérisation.*

Modèle - *Model*

Un modèle est une représentation simplifiée d'un système complexe en vue de le comprendre et/ou d'en prédire le comportement.

p. ex. *le cycle de vie d'un produit*

Outil - *Tool*

Un outil est un logiciel, application, ou une base de données permettant l'analyse d'un modèle en fonction d'une ou plusieurs méthodes préalablement choisies.

p. ex. *l'outil Simapro permet de modéliser le cycle de vie d'un produit en suivant des règles fournit par la méthode d'inventaire du cycle de vie choisie*

Indicateur - *Indicator*

Un paramètre ou une valeur dérivée de paramètres vise à fournir une indication ou à décrire l'état d'un phénomène avec une signification qui va au-delà de celle associée à la valeur de ce paramètre.

p. ex. *l'indicateur « raréfaction des énergies fossiles » est mesuré par le paramètre « mégajoules consommées ».*

Appendice 2: Statistical analysis

Table 17: Absolute contribution of variables to the factorial axe

		Absolute contribution			
Variables		Axis 1	Axis 2	Axis 3	Axis 4
Diesel consumption	DC	16	715	786	107
Fuel oil consumption	FC	23	47	185	221
Water consumption	WC	233	96	263	489
Chicks consumption	CC	7	31	549	1
Fresh litter consumption	FLC	33	238	297	738
Gas consumption	GC	41	576	21	542
Electricity consumption	EC	618	60	**1005**	353
Density	DE	30	316	58	**1932**
Feed conversion efficiency	FCE	722	174	34	689
Mortality rate	MR	285	746	183	152
Average age at slaughter	AAS	**894**	390	229	368
Average daily gain	ADG	**771**	**1004**	70	628
Average live weight at slaughter	ALWS	162	**1078**	8	446
Overall productivity	OP	255	**1298**	56	668
Electricity consumption / m²	ECM	749	30	483	642
Average age of buildings on the farm	ABA	118	47	92	565
Quality score of building	QBS	**959**	463	31	109
Quality score of heating system	QHS	652	210	93	17
Quality score of feeding system	QFS	722	47	535	186
Quality score of ventilation system	QVS	**941**	128	444	3
Quality score of atmosphere control equipment	QACE	**1034**	363	93	194
Total building surface	TBS	281	1	458	799
Average building surface	ABS	227	**1025**	**1171**	17
Altitude	ALT	10	11	**1956**	24
Quantity of live weight chickens produce	QCP	218	**908**	**898**	111

For absolute contribution, values of variables above the mean value of the axis plus standard deviation are in bold

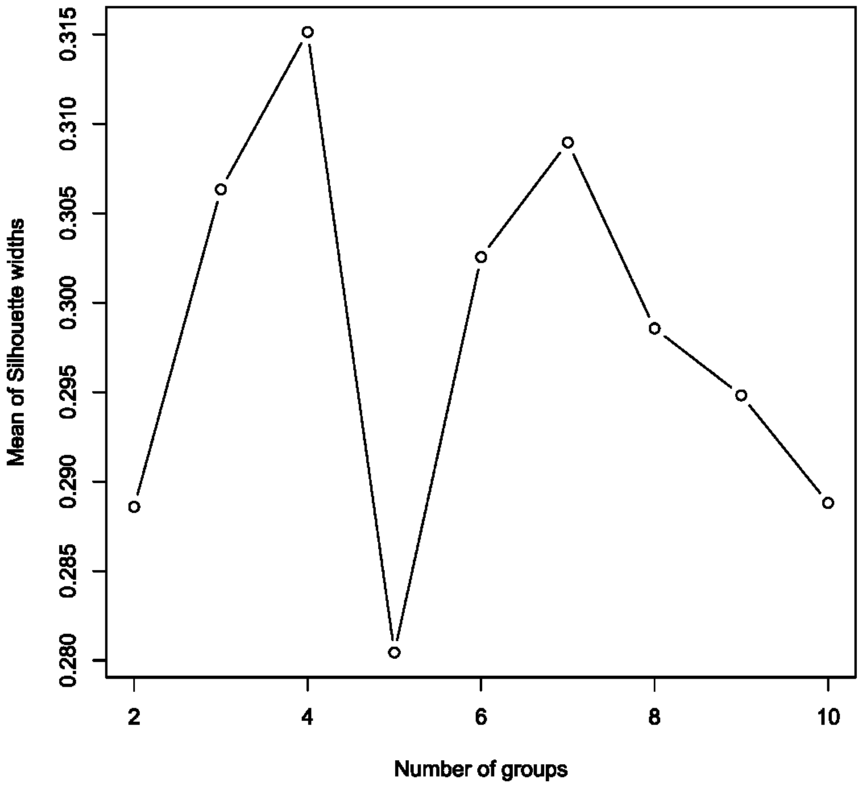

Figure 21: Graphical display of Silhouette index for 2 to 10 clusters

Appendice 3: Input Output Analysis

1. The relationship between final demand and production.

The input-output tables are based on a balanced accounting relationship between supply and use for goods and services in a country:

$$P + X = C^I + C^F + E + F \tag{1}$$

Where P is production, X is imports, C^I is intermediate consumption, C^F is final consumption, E is exports and F gross fixed capital formation and stock variation.

We posit the hypothesis of an economy initially without imports and the elements of final demand D are aggregated to convey this relationship in a simplified format:

$$P = C^I + D \tag{2}$$

With n sectors in the economy, balance can be written in matrix form:

$$[D] = [P] - [C^I] \tag{3}$$

If the technology has fixed coefficients, we have the technical coefficient:

$$a_{ij} = \frac{C_i^{I,j}}{P_j} \tag{4}$$

and [A] the square matrix of the technical coefficients, we have:

$$[C^I] = [A].[P] \tag{5}$$

The supply-use balance can then be written:

$$[D] = [P] - [A].[P] \text{ Or } [D] = [I - A].[P] \text{ Or } [P] = [I - A]^{-1}.[D] \tag{6}$$

2. The relationship between value-added and final demand.

At the macroeconomic level the value-added is conventionally calculated as follows:

$$VA = P - C^I \tag{7}$$

With (4) and (5), we obtain:

$VA_j = P_j - P_j \sum_{i=1}^{n} a_{ij}$ Or $VA_j = P_j . (1 - \sum_{i=1}^{n} a_{ij})$ (8)

Where $(1 - \sum_{i=1}^{n} a_{ij})$ is the value-added coefficient noted v_j

Or in matrix form:

$$[VA] = [V'].[P] \quad (9)$$

From the balances (5) and (8), we obtain:

$$[VA] = [V'].[I - A]^{-1}.[D] \quad (10)$$

The matrix [W_{VA}] gives the value-added coefficient in the composition of final demand:

$$[W_{VA}] = [V'].[I - A]^{-1} \quad (11)$$

3. Introduction of imports

We must change the input-output table because it does not distinguish between domestic intermediate consumption and imported intermediate consumption. The imports X are either used in intermediate consumption ($X_{CI} = C^I_X$) or constitute a final demand ($X_D = D_X$). The balance between supply and use thus becomes:

$$P + (X_{CI} + X_D) = (C^I_{INT} + C^I_X) + D_{INT} + D_X \quad (12)$$

The imported intermediate consumption coefficient by industry is calculated:

$b_{ij} = \frac{X_j}{C_i^{I,j} + C_i^{F,j}}$ with [B] the matrix of intermediate consumption coefficients. (13)

The imported intermediate consumption by sector gives:

$$[C^I_{X,j}] = [B].[C^I_j] \quad (14)$$

Local intermediate consumption is calculated by sector:

$[C^I_{INT}] = [C^I] - [C^I_X]$ to be used in the equation (4)
(15)

To obtain the total value-added by sector, the sectoral breakdown of customs duties, trade margins on imported products and trade margins on local products must be added.

$$VA_T = VA + DtD_X + MC_X + MC_{INT}$$
(16)

Customs duties on imports are calculated as follows:

$$\text{DtDx} = DtD.X/C_{X,j}^{I} \quad (17)$$

To calculate profit margins, first the pre-tax production value is calculated:

$$P_{HT} = P - TVA_{nd} - I_{imp} - I_{exp} - I_{autre} - SP \quad (18)$$

The profit margin on imported MC_X and local MC_{INT} products is then calculated as follows:

$$[MC_X] = \frac{[C_X^I]\times[MC]}{P_{HT}} \quad \text{And} \quad [MC_{INT}] = \frac{[C_{INT}^I]\times[MC]}{P_{HT}}$$
(19)

With MC the profit margin, P_{HT} production not including tax.

The available production is then:

$$P = C_X^I + C_{INT}^I + VA_T \text{ to be used in equation (4)} \quad (20)$$

The embedded value-added is broken down in the same way as the value-added of the operating statement into gross income SB_{inc}, embedded social security contributions $CS_{inc,}$ embedded tax $IP_{inc,}$ subsidy on embedded production SP_{inc} and embedded gross operating surplus EB_{inc}:

$$VA_{inc} = SB_{inc} + CS_{inc} + IP_{inc} + SP_{inc} + EB_{inc} \quad (21)$$

4. The relationship between intermediate imports and final demand

The intermediate import coefficient b_{ij} in final demand is calculated using the relationship (14)

$b'_{ij} = \frac{C_{X,j}^{I}}{P}$ Where [B '] is the matrix of intermediate consumption coefficients in the final demand.

The matrix $[W_X]$ gives the import coefficient in the composition of the final demand:

$$[W_X] = [B'].[I - A]^{-1} \tag{22}$$

Increased local production is then broken down between increased imports and increased added value. For this we multiply each item in the consolidated account of the sector by the coefficients of the corresponding sector of the matrix.

Appendice 4: Review/Communication LCM Berlin

Towards the use of LCA as an approach to evaluate contribution of agriculture to sustainable development

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Abstract

Development of sustainable agriculture is essential for maintaining ecosystem services and human well-being facing significant human population growth. Decision-makers must now take into account not only economic performance but also environmental compliance and social responsibility of supply chains. Agriculture differs from other sectors such as industry in the sense that it provides numerous ecosystem services such as landscape maintenance, social cohesion, and rural exodus limitation. Life Cycle Analysis (LCA) is largely presented as a standardized method for environmental impact assessment of a product or a process. Implementation of LCA generally points out only the negative impact of agricultural activities. In this paper we suggest that LCA should be considered not as a standardized method - with the risk of limiting its implementation domain - but as an approach offering the possibility to integrate the three dimensions of sustainable development. LCA can use numerous impact assessment methodologies produced by various disciplines (agronomy, social sciences, economy, etc.). Particular attention is needed on methodological problems encountered on allocation, assessment scale and system boundaries in order to build an integrated view of products and processes.

1. Introduction

Sustainable development returns to the concepts of environmental, economic and social durability (UNCED, 1992). Assessment in agriculture has always been complicated by multiple links between ecosystems and humans. It is one of the anthropic activities that have the strongest link with environment. Through it, ecosystem provides many services to humans. They are known as ecosystemic services (food, aesthetics, leisure activities, etc.). On the other hand, humans generate via agricultural activities negative externalities on the environment (pollution, loss of biodiversity) and unlike the majority of other industry branches, produced externalities can also be positive (ex: carbon sequestration, biodiversity conservation) (Swinton *et al.*, 2007).

Sustainability assessment often focuses on negative externalities. In the last decades, the increase of impacts frequency became a big concern, which makes environmental dimension unavoidable in decision-making process. Tools for decision-making were thus elaborated. Life Cycle Analysis became a privileged approach because of its holistic and systemic vision of the system. However, classic tools (Attributional LCA, carbon accounting) based on this approach only focus on potential environmental impacts. In 2006, a FAO report estimates that livestock sector is responsible for 18% of the total entropic gas emissions (Steinfeld *et al.*, 2006). Other reports (FAO, 2010) showed only the negative impact of agriculture on environment. The published global results do not evaluate neither positive nor economic and social performance of the whole product. Consideration of those externalities and dimensions through LCA approach becomes necessary for a coherent decision making. In this paper we present a review of several methods used in environmental, economic and social field that could be useful in the research field of sustainable LCA. We will try also to point out how those methods could improve assessment of a sustainable agriculture.

2. Environmental assessment perspectives in agriculture

Crops and animal productions have been widely evaluated (de Vries and de Boer, 2010). Most of these assessments were carried out in order to establish environmental impact references for the agricultural sector (Basset-Mens and van der Werf, 2005; Cederberg and Flysjö, 2004; Pelletier, 2008). Classical Attributional Life Cycle Assessment (ALCA) allows system quantification of pollution and resource flows attributed to a functional unit (Rebitzer *et al.*, 2004). Allocation is the standard procedure (ISO 14041) applied in order to allocate pollution and resource flows of a multi-functional process (ISO, 1998). However, it is one of the most controversial issues of LCA because of its arbitrary appliance (Kloepffer, 2008), particularly in agriculture that is highly multi-functional and where co-products can have significant roles in the main product system and in adjacent product systems. For instance, manure produced by livestock systems is reused by plant production systems, which avoids mineral fertilizer consumption. The relatively tight system boundaries of classic LCA do not consider the consequences resulting from the co-product use in other product systems. That should allow a more accurate durability assessment.

By expanding the system to include alternative production ways using co-products, the system expansion method is an alternative within the use of consequential LCA. Table 1 provides an overview of several differences between CLCA and ALCA. CLCA development is currently on going. A few studies exist in agricultural field but some cases of avoided co-product allocation are shown. For instance, Thrane (2006) expands the system boundaries in flat fish filet assessment from Danish fisheries to avoid by-catch, fish mince and fish offal allocation. Those co-products substitute respectively catch in other Danish fisheries that target these species, pork meat and soy-protein. The principles of the system expansion that were followed here, and in most cases studied in consequential LCA field, are described by Ekvall and Weidema (2004). In another study, Thomassen *et al.* (2008) showed results from an attributional LCA and a consequential LCA on a dairy farm production system. System expansion is applied on co-products of milk life cycle: soybean and beef meat impacts that are converted into palm oil, pork and beef meat avoided impacts. The conclusions were that it is possible to perform both LCA types, however, the choice of ALCA or CLCA must be done according to the study goals. CLCA should be used to assess a change in demand whereas ALCA to assess environmental burdens of a product. According to Dalgaard *et al.* (2008) it might be easier to handle CLCA if more effort is put into the development of marginal data. Indeed, this approach requires the existence of alternative systems to substitute co-products (Azapagic and Clift, 1999). The use of system expansion and marginal data still induces some important limitations concerning completeness, accuracy and relevance (Ekvall, 2002). The use of CLCA in agriculture assessment could allow to avoid allocation problems. This way, positive impacts for each indicator are quantified and displayed (Thrane, 2006).

3. Extension to economic and social aspects

In addition to these interactions with the environment, agriculture can have many social and economic impacts and can also return economic and social services that can be evaluated at very different levels. Focusing only on environmental impacts limits the use of LCA in the decision making process. To be sustainable a company must be economically sustainable and able to keep competing for advantages on its products. Figure 22 shows a set of three indicators that could be relevant for supply chain assessment in agriculture. The actual issue is to point out methodologies available in literature and to compare assessment scales, system boundaries, and purpose of application.

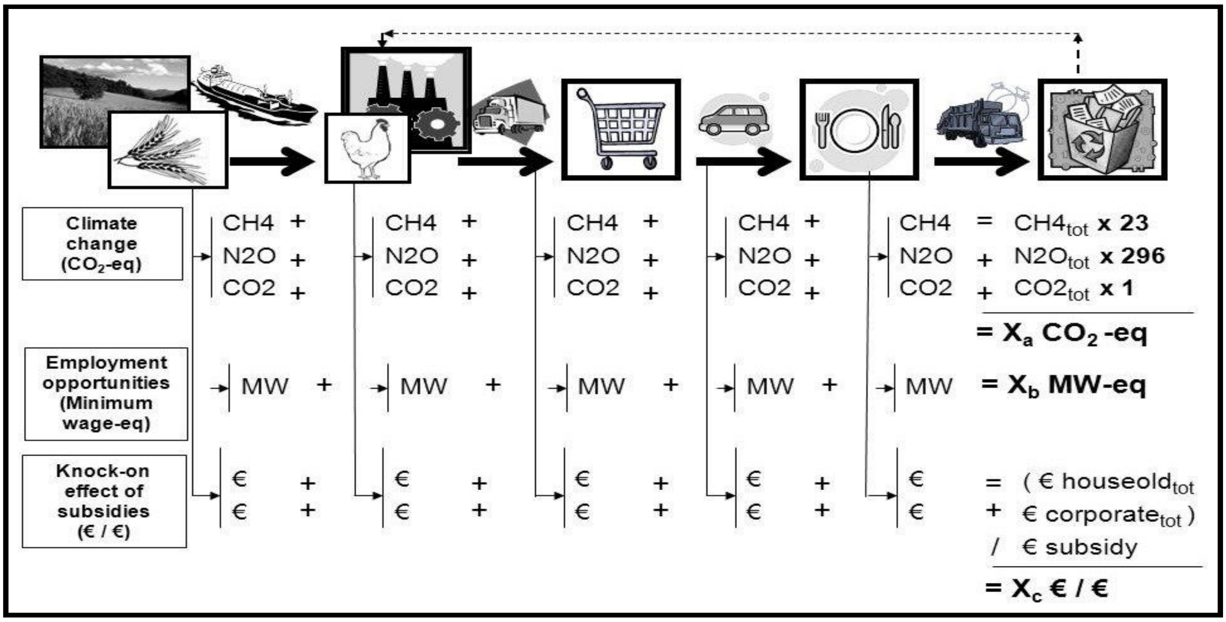

Figure 22: Example of economic and social aspects integration in LCA of a livestock supply chain

3.1. Guidelines for economic dimension

Many methods and their applications can be found in the economic evaluation field but few share ideas with life cycle thinking. Among the attempts to carry out economic and environmental assessment, the most integrated approach is Environmental Life Cycle Costing (ELCC) (Hunkeler *et al.*, 2011). It estimates, at product scale, the economic performance of a product and allows multiple points of view. The costs evaluated are linked to real monetary flows and include use, end-of-life, and hidden costs. It allows to evaluate whether or not a product developed in a sustainable way will be profitable and has a reasonable price for consumers. At another level, Cost Benefit Analysis (CBA) allows to assess direct and indirect economic costs and benefits of a project. It was developed separately from LCA but shares the same objective to provide holistic assessment of human activities. Weidema (2006) emphasizes that much can be gained from both, however, his approach was quite taken up in literature. Other approach known as Input-Output Life-Cycle Assessment (IOA - LCA) (Lenzen, 2000) combines Input- Output Analysis with LCA. IOA is used to analyze the flows of goods and services between sectors within an economy. Efforts are being made in this field by the IOA-LCA community (Suh and Nakamura, 2007) because it can bring improvement in various areas of LCA. The economic dimension of sustainability can also be evaluated at a regional or national scale with Social Accounting Matrix (SAM). SAM has the advantage to measure aggregated impacts along the supply chain, taking into consideration all stakeholders (Basquin, 2002; Parrot *et al.*, 2004). Another recent work carried out by Binder *et al.* (2008)

combines environmental and socio-economic indicators in a Sustainability Solution Space. This approach provides a multi criteria decision analysis based on stakeholder participation and allows benchmarking.

All presented approaches bring relevant elements to economic LCA construction. Further work might be necessary to highlight connections that exist between them and LCA approach.

3.2. Guidelines for social dimension

Several studies have been trying to integrate the social aspect in LCA but SLCA is still in its infancy (Dreyer *et al.*, 2006; Hunkeler, 2006; Rebitzer *et al.*, 2004). Different ways have been explored with different scales, functional units, and indicators (see Table 18). A lot of methodological problems remain unsolved, but those studies point out interesting leads for further research. The use of midpoint or endpoint indicators is, for example, still discussed within scientist's community. Grießhammer *et al.* (2006) argued that midpoint indicators should be used because they are easier to comprehend for the decision makers. Weidema (2006) suggests the use of a procedure that converts all impacts into a QALY (Quality Adjusted Life Years) as a measure of human well-being. Kloepffer (2008) suggests that impacts have to be quantitatively linked to a functional unit. Hunkeler (2006) refers to a single impact category based on working hours and evaluates social impacts from the labor income. Franze and Ciroth (2011) presents the first case study based on « Guidelines for Social Life Cycle Assessment of products » elaborated by the UNEP/SETAC working group (Benoît and Mazijn, 2009). A conclusion of this study shows that there is a strong difficulty to find appropriate indicators. These results confirm several problems identified concerning social integration in LCA. According to Hunkeler (2006) “More than 200 societal midpoint impact indicators exist, which may lower probability of obtaining agreement on their selection and valuation in actual use”. Moreover “Data needs are greatly increased with non-environmental, company-specific data or region-specific data”, according to Dreyer *et al.* (2006).

Table 18 : Overview of potential methods that can be integrated in LCA for agriculture sustainability assessment

Method	System boundaries	Data inventory	Scale	e.g. of indicators	Study
Environmental dimension					
ALCA	Supply Chain	Resources and processes directly used in life cycle of the product	Global	Climate change, Energy use, Acidification	Cedeberg [7]
CLCA	Supply Chain	Resources and processes directly and indirectly affected by a change in the output of a product	Global	Climate change, Energy use, Acidification	Thomassen [14]
Economic dimension					
ELCC	Supply Chain	All internal and external costs associated with a product	Product	Climate change, Energy use, Acidification	Hunkeler [18]
I-OA	Industry	All monetary values of an industry's inputs and output	Regional /National	-	Lenzen [20]
C-BA	Project	All costs and benefits of a project	Regional /National	Economic costs and benefits to different agents, changes in capital stocks	Weidema [19]
SAM	Part of Supply Chain	Income and economic flows between different institutional units	Regional /National	Total Value Added, Employee Comp VA; Profits VA	Basquin [22]
Social dimension					
S-LCA	Supply Chain	Global burden of well-being	Regional /National	Child labor, Trafficking, Excessive work, Crime victim compensation	Weidema [19]
S-LCA	Supply Chain	The most important companies in the product chain	Regional /National	Wages, Stability of employment, Job creation	Dreyer [25]
S-LCA	Supply Chain	Employment hours of life-cycle stages	Regional /National	Housing, Health care, Education, Necessities	Hunkeler [26]
S-LCA	Supply Chain	Social Hot Spot and classic environmental system boundaries	Regional /National	Forced labor, Fair competition	Franze [28]

4. Discussion and conclusions

All methods presented in Table 18 provide several interesting indicators and results. For environmental dimension, CLCA allows construction of avoided impact indicators. It implies making hypothesis on which alternative product impact could replace the co-product impact. However this seems more relevant in agriculture assessment than allocation because of the high value added of co-products. Economic field brings several indicators for assessing economic contribution of agriculture. Value added distribution among stakeholders and contribution to GDP (Gross Domestic Product) assessed with IOA methods are particularly relevant in this way. Advances in social LCA show a large panel of indicators, from employee well-being to job creation.

Nevertheless, this multiplicity of indicators leads to some methodological problems. One of them is the presence of various assessment scales. For economic dimension, assessment can focus whether on the economic product performance or the added value created along the supply chain. At product scale, ELCC is the most relevant approach for sustainable company assessment, but there is no relevance when it comes to assess world society (Jorgensen *et al.*, 2010). At regional scale, IOA or SAM can be useful because it takes all stakeholders into account. This problem is also founded in SLCA, which is highly site-specific. Decision-makers goals can be to evaluate the respect of workers' rights or about how many jobs are created at each step of the product chain at regional scale.

Another issue is about the delimitation of system boundaries. The system boundary defines the start and the end of the material flows which are accounted. Setting those boundaries is a persistent problem in ELCA (Reap *et al.*, 2008) as it can be noticed regarding the criticisms towards the lack of objectivity allowed by ISO standards (Suh *et al.*, 2004). It is confirmed for agricultural system assessment, where contrarily to other sectors as industry, multiplicity of biological processes involved complicates the identification of all flows between processes and the environment. Although it seems to focus on supply chain for most of the methods seen in Table 18, conjunction of system boundaries might be harder when it comes to integrate economic and social aspects in LCA. Indeed, most impacts on people are independent of the physical processes (Dreyer *et al.*, 2006).

There is a significant variety of methods that could be used to develop social and economic indicators. However, it requires more research before leading to a standardized and generic tool as environmental LCA. In the short term, methodological connections highlighted between current methods in economic and social sciences field and LCA must be applied on real case studies in order to prospect a various set of scenarios. Learning those bases will allow to develop appropriate sets of indicators. Researches in this field should give priority focus on agricultural case study. It is the anthropic activity that will provide the biggest part of human basic needs and will feed the nine billion people tomorrow.

Appendice 5: Communication LCA Food

Nitrogen content allocation to handle co-products in livestock systems – Case study on a poultry supply chain

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ABSTRACT

In food sectors processes along the life cycle of a product can be multifunctional. ISO standards for Life Cycle Assessment specify rules in order to allocate the environmental burden between co-products. First recommendation is to avoid allocation with subdivision or system expansion. However when it is not possible, emissions and raw materials consumption allocation must reflect the physical relationship between products. Usually economic, mass or gross energy content allocation rules are used. But several problems remain for agricultural productions: economic allocation is highly sensitive to market fluctuations and mass and gross energy content allocations could lead to counter-intuitive results. Co-products may indeed weight or contain more energy than the product under study itself. For these points, allocation has always been considered as one of the most controversial issues in LCA and particularly for agricultural systems (Audsley *et al.*, 1997).

Livestock productions are highly multifunctional (e.g. dairy farming produces milk, meat, and manure). In industrialised countries, its main function is the provision of proteins for human diet and its major environmental problems are linked to high nitrogen (N) losses occurring during manure management. For these reasons, we proposed in this study to compare results obtained with allocation rule based on product's nitrogen content with other classical allocation rules (Mass and economic allocation and economic allocation with system expansion to manure use). Effects of these different allocation rules were applied on a poultry supply chain in La Réunion (French Tropical Island). Allocation is applied at different production stages: i) breeders rearing where co-products are breeders and litter, ii) layer production with hatching eggs, cull animals and unfertilised eggs, iv) broiler production with broiler and litter, v) slaughterhouse vi) Incineration plant with production of feathers and

blood meal as fertilizer and wastes management. For economic allocation we use the product price at process level. Manure price was estimated by on farm surveys. For system expansion, poultry litter was in this case replaced by mineral fertilizer which is imported from mainland France over ten thousand kilometres. The functional unit was defined as one tonne of chicken carcass at slaughterhouse gate. System boundaries are shown in Figure 23. LCA was performed using CML 2 Baseline 2000 for Global Warming (GW), Energy Use (EU), Acidification Potential (AP) and Eutrophication Potential (EP) impact categories, and Cumulative Energy Demand method v1.08, all implemented in Simapro Software.

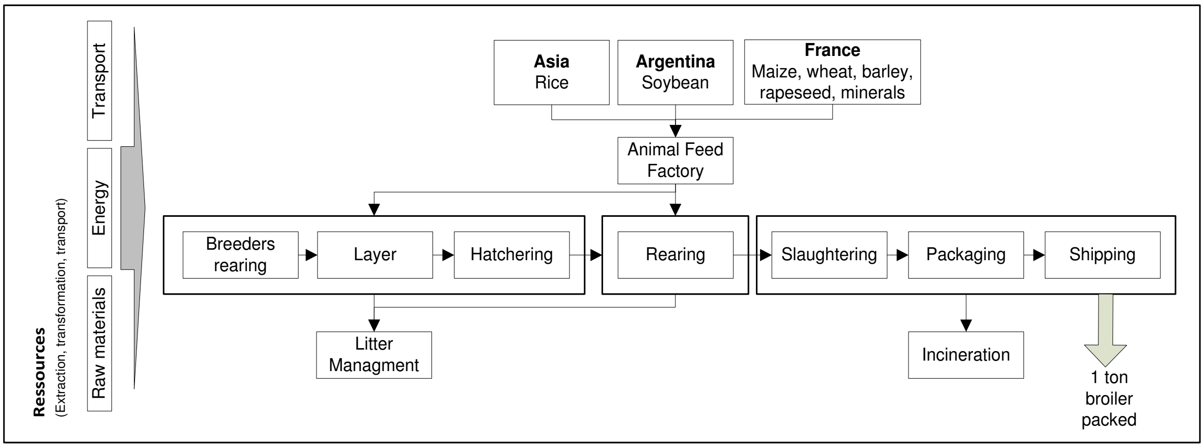

Figure 23: System boundaries for a cradle to slaughterhouse gate for 1 ton of broiler packed ready for transport

Impacts categories were significantly sensitive to the allocation rule (See Figure 24). Economic allocation leads to higher impact over all categories. System expansion reduced by 10% GW and EU and 5% EP and AP. Nitrogen content and mass allocation show results around 25% and 30% lower than economic allocation respectively. Most of differences were observed at farming stage with manure management.

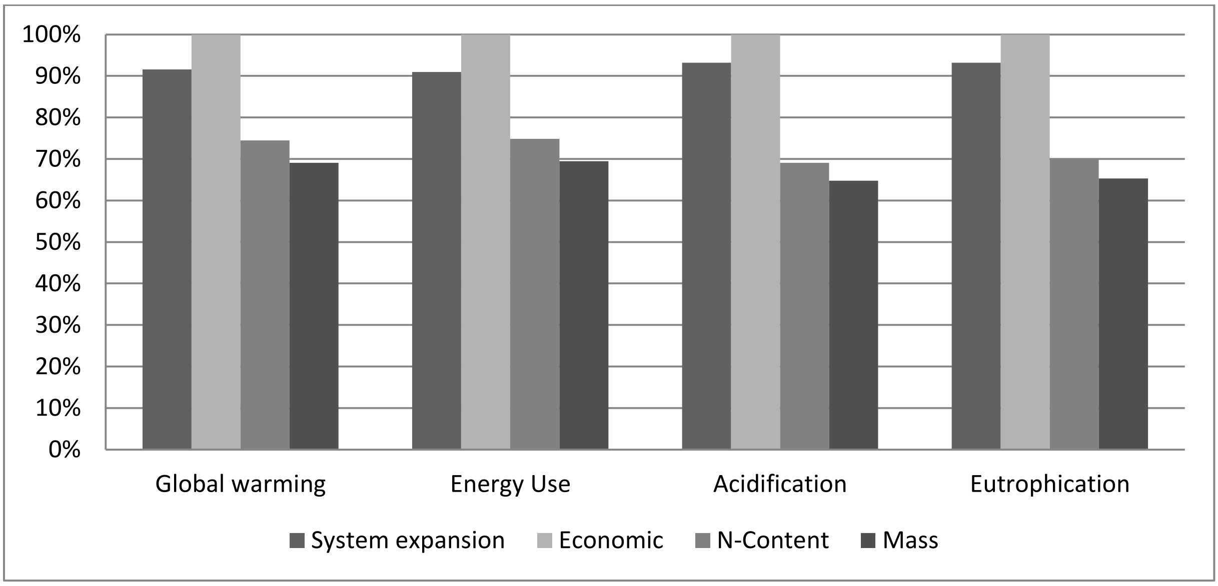

Figure 24: Results of impact assessment for 1 ton of broiler packed depending on the chosen allocation method

Manure management patterns could differ a lot within a same territory that it is often difficult to establish a reasonable cost for economic allocation. Mass allocation has to be avoided because litter weight highly depends on moisture content. System expansion is not recommended in this case because of additionally maritime transport burden. Nitrogen content allocation seems to be an interesting option for livestock production environmental assessment and is in the range of other allocation rules. Finally, the choice of allocation rule for agricultural systems always depends on the manure value in the given system. Using this allocation rule, poultry litter takes however a high part of environmental burden of meat production, which seems consistent regarding its high value all over the world.

Keywords: LCA, Allocation, Poultry, Nitrogen, Reunion Island

Nitrogen content allocation to handle co-products in livestock systems – Case study on a poultry supply chain

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OCTOBER 1-4 2012 SAINT-MALO FRANCE

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PURPOSE

Livestock productions are highly multifunctional (e.g. dairy farming produces milk, meat, and manure). In industrialized countries, its main function is the provision of proteins for human diet and its major environmental problems are linked to high nitrogen (N) losses occurring during manure management.

Allocation has always been considered as one of the most controversial issues in LCA and particularly for agricultural systems (Audsley *et al.*, 1997).

We proposed in this study to evaluate an allocation method based on nitrogen content of products.

Allocation is applied at different production stages:
- Breeders rearing ⇨Breeders and litter
- Layer production ⇨Hatching eggs, cull animals and unfertilized eggs
- Broiler production ⇨Broiler and litter
- Slaughterhouse ⇨Poultry and turkey

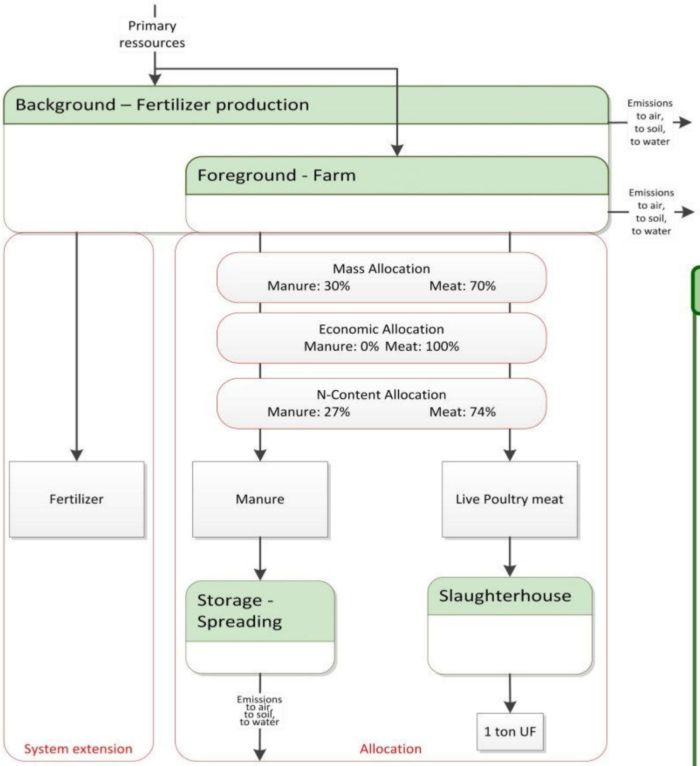
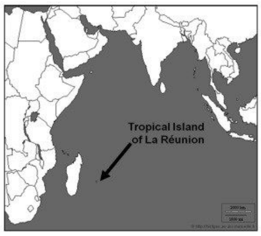


Figure 1: Production system and allocation rules definitions



MATERIAL and METHODS

Effects of these different allocation methods were applied on a poultry supply chain in La Réunion Island (French Tropical Island).

The functional unit was defined as one tonne of chicken carcass at slaughterhouse gate.

LCA was performed using:
– CML 2 Baseline 2000 for Global Warming (GW), Acidification Potential (AP) and Eutrophication Potential (EP) impact categories,
– Cumulative Energy Demand method v1.08 for Energy Use (EU)
, all implemented in Simapro Software.

⇨ For economic allocation we use the product price at process level. Manure price was estimated by on farm surveys.

⇨ For system expansion, poultry litter was in this case replaced by mineral fertilizer which is imported from mainland France over ten thousand kilometers.

RESULTS

⇨ All impact categories were sensitive to allocation rules

⇨ Economic allocation induced the higher impact over all categories

⇨ System expansion allowed 10% offset for GW and EU and 5% for EP and AP

⇨ Nitrogen content and mass allocation show results around 25% and 30% lower than economic allocation

⇨ Major differences were observed at farming stage due to manure management

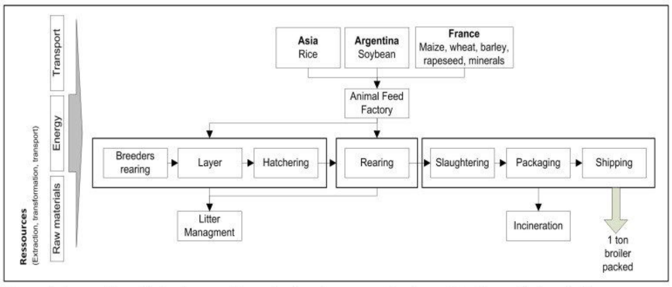


Figure 2: System boundaries for a cradle to slaughterhouse gate for 1 ton of broiler packed ready for transport

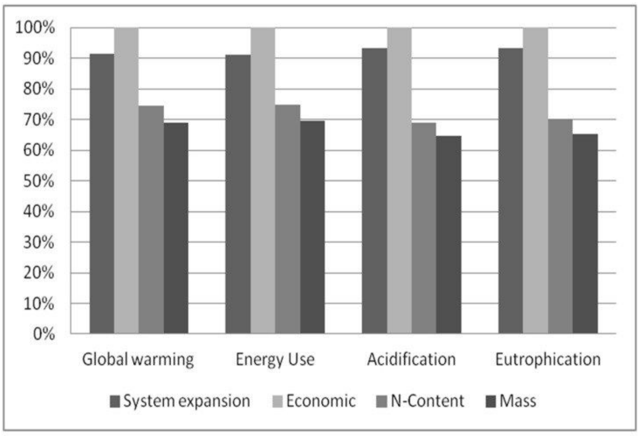


Figure 3: Results of impact assessment for 1 ton of broiler packed depending on the chosen allocation

DISCUSSION AND CONCLUSION

- Manure management patterns could vary a lot within a same territory
  - Difficulty to establish a reasonable cost for economic allocation
- Mass allocation must be avoided
  - Litter weight highly depends on moisture content
- So, when system expansion is not possible
  - Nitrogen content allocation seems to be an interesting option, for livestock production environmental assessment

Using this allocation rule, chicken manure takes a high part of environmental burden of meat production, which seems consistent regarding its high value all over the world

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Appendice 6: Affichage environnemental gamme Grand Matin

Grand Matin

Faites entrer la nature dans votre vie.

Accueil | Notre Démarche | L'Indice Carbone | Les Eco-gestes

Comment est calculé l'indice carbone ?

La fabrication et l'emballage d'un produit émet une certaine quantité de gaz à effet de serre. L'indice carbone est ainsi une estimation de cette quantité de gaz à effet de serre émise lors des principales étapes du cycle de vie du produit : production, transformation, emballage, transport… Il est exprimé en gramme équivalent CO2 par kilo de produit.
Pour les étapes réalisées sur l'île de La Réunion – fabrication des aliments; accouvage; élevage; abattage; transformation et expédition des produits, les données sont issues des bilans carbone des entreprises de la filière avicole. Pour les étapes complémentaires, ce sont des informations issues des bases de données nationales qui ont été utilisées.

Indice CO2

Produit Grand Matin	***g de CO2 pour 100g***
Poulet Noir de Cimendef	557,6
Poulet Noir de Cimendef effilé	566,9
Cuisses Noir de Cimendef x2	722,3
Filets Noir de Cimendef x2	1024,6
Coq Péi	574,4
Civet Coq Péi	584,1
Civet Pintade Péi	541
Pintade Péi	541,6
Poulet Jaune Péi	365,3
Cuisses de Poulet x4	366,7
Hauts de cuisse de Poulet x4	366
Pilons de Poulet x5	419,5
Poulet Fumé *Les Fumets des Salazes*	340,5
Saucisses de Volaille Fumée x3 *Les Fumets des Salazes*	633,5
Carri Poulet	255,7
Carri Poulet Fumé *Les Fumets des Salazes*	339,6

Source : *Etude menée en collaboration avec le CIRAD*

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http://www.grand-matin.re/

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